UNDERGROUND COAL MINE CONVEYOR SYSTEMS: A REVIEW OF AVAILABLE TECHNOLOGY AND INDUSTRY NEEDS FOR THE PREVENTION, DETECTION AND CONTROL OF FIRES.

FINAL REPORT
BY
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EXECUTIVE SUMMARY

Under the auspices of the Canada Centre for Mineral and Energy Technology, Energy, Mines and Resources, Canada, Robinson Dames & Moore has conducted a review of available technology and industry needs for the prevention, detection and control of fires in underground coal mine conveyor systems to achieve the following objectives:

- A ranking, in terms of relative risk, of the various components of standard underground conveyor installations.
- A summary of commercially available technology and recent research findings relevant to the prevention, detection, and control of conveyor fires and smouldering incidents.
- An examination of monitoring with computer-based remotely operated systems and a comparison of such systems with labor intensive site monitoring and with combined approaches.
- A summary of present and future Canadian industry needs.

The study concludes that idler rollers, mounted on the intermediate structure of the conveyor, constitute the greatest hazard and cause of fires and identifies the introduction of fire-resistant grease, self-locking idlers, and infra-red scanning as the most recent technological developments to reduce the fire risks.

The study reviews the commercially available technology for fire protection, prevention, detection, and suppression in underground coal mines and identifies differences between Canada and other countries in the application of the technology. A summary, of present and future Canadian needs, identifies specific matters which appear to merit more detailed consideration either in Canadian regulations or codes of practice, or as topics for further research and development.

RÉSUMÉ ADMINISTRATIF

Sous l'égide du Centre canadien de la technologie des minéraux et de l'énergie et celle d'Énergie, Mines et Ressources Canada, Robinson Dames & Moore a mené une étude sur la technologie disponible et les besoins de l'industrie en matière de prévention, de détection et de contrôle des incendies des convoyeurs souterrains dans les mines de charbon afin d'atteindre les objectifs suivants:

- Un classement, en fonction du risque relatif, des divers éléments d'installations d'un convoyeur souterrain standard.

- Un résumé de la technologie disponible sur le marché et des plus récents résultats de recherches ayant trait à la prévention, la détection, et au contrôle des incendies de convoyeur et des incidents de combustion lente.

- Un examen du contrôle effectué à l'aide de systèmes commandés à distance et informatisés, et une comparaison de ces systèmes avec le contrôle intensif sur place du travail et avec des approches combinées.

- Un résumé des besoins présents et futurs de l'industrie canadienne.

L'étude conclut que les roues parasites montées sur la structure intermédiaire des convoyeurs, constituent le plus grand danger et la plus grande cause d'incendie et elle identifie l'introduction de la graisse ignifuge, de poulies-guides à blocage automatique, et de l'exploration à l'infra-rouge comme les plus récents avancements technologiques permettant de réduire les risques d'incendies.

L'étude examine la technologie disponible sur le marché pour la protection, la prévention, la détection et la suppression des incendies dans les mines de charbons souterraines et identifie les différences entre le Canada et les autres pays dans la mise en application de la technologie. Un résumé des besoins présents et futurs illustre les points particuliers qui semblent mériter une plus grande attention, que ce soit en tant que lois ou codes de pratiques canadiens, ou en tant qu'objet de recherches approfondies ou de perfectionnement.

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1. INTRODUCTION

1.1 STUDY OBJECTIVES

This study, entitled "Underground Coal Mine Conveyor Systems: A Review of Available Technology and Industry Needs for the Prevention, Detection, and Control of Fires", has been conducted by Robinson Dames & Moore to achieve the following objectives:

- A ranking, in terms of relative risk, of the various components of standard underground conveyor installations.
- A summary of commercially available technology and recent research findings relevant to the prevention, detection, and control of conveyor fires and smouldering incidents.
- An examination of monitoring with computer-based remotely operated systems and a comparison of such systems with labor intensive site monitoring and with combined approaches.
- A summary of present and future Canadian industry needs.

1.2 STUDY PROCEDURES

A computer-assisted bibliography search for published literature, relevant to past experience with conveyor fires in underground coal mines and to available technology and recent research findings relevant to the prevention, detection, and control of conveyor fires and smouldering incidents, was conducted. The data bases, which were searched, comprised CANMET, IEA Coal Research, NTIS, COMPENDEX, ISMEC-Mechanical Engineering, and Ei-Engineering Meetings. A bibliography of literature relevant to this study was compiled of 180 references and is included at Appendix 1. Copies of the relevant literature were obtained from libraries and other sources and, following a detailed review, have been extensively referenced in this report.

In addition to the bibliography search, extensive correspondence and telephone conversations were entered into with potential sources of information relevant to the objectives of this study. A complete list of those with whom Robinson Dames & Moore corresponded or conversed by telephone is provided in Appendix 2.

On December 11/12, 1984, Robinson Dames & Moore met with Mr. G.A. Haslett, the CANMET Scientific Authority for this project, to discuss the project requirements and to review progress. The meeting was found by Robinson Dames & Moore to be extremely beneficial to its conduct of the study.

2. RELATIVE FIRE RISKS OF BELT CONVEYOR COMPONENTS

2.1 CONVEYOR ASSEMBLIES

The conventional belt conveyor used in underground coal mines is comprised of a number of components as follows:

- The drive-head which includes motors, couplings, gearboxes, brakes, and driven-rollers which move the belt by frictional contact.
- Tensioning equipment to impart sufficient longitudinal tension in the belt to enable the frictional contact between the driven-rollers and the belt to drive the belt without excessive slippage.
- The tail-end or return unit comprising an assembly for mounting an idler roller.
- Intermediate support structure between the drive-head and tail-end which supports top and bottom roller assemblies to impart a troughed-shape to the belt for load carrying purposes and to prevent belt sag.
- The conveyor belting which is endless and traverses twice the distance between the drive-head and the tail-end, and is driven by friction between the belt and the driven-rollers at the drive-head.

Belt conveyors are widely used in underground coal mines for the transport of coal, rock, and personnel. Over 6,000 belt conveyors are currently in use in the United Kingdom (Duke, 1980). In Canada, and in most European countries, most belt conveyors in underground coal mines are installed in intake airways and operate under relatively hazardous conditions of forced ventilation, coal dust, and a fuel-rich environment (Cutler and Currie, 1979). The combination of the environmental conditions,

in which conveyor belts operate, the intrinsic problems of the many moving parts within conveyor assemblies which may jam, or breakdown and form a source of frictional heating, and the relatively unstable nature of the roadways in which conveyors are installed, provides a substantial fire hazard.

2.2 UNDERGROUND FIRES INVOLVING CONVEYOR SYSTEMS

Statistical evidence of the incidence of conveyor fires varies substantially from country to country and may depend on the legislative requirements for the reporting of dangerous occurrences. Such evidence as there is available may, to some extent, be unrepresentative of the current hazards of belt conveyors due to substantial technical improvements in the design of conveyor components, the manufacture and introduction into coal mines of fire-resistant belting and other materials, and the use of automatic fire detection and suppression equipment. Based on the available literature, it is possible, however, to reach some conclusions of the relative fire risks of belt conveyor components from a consideration of data on a national basis.

2.2.1 United States

McDonald and Pomeroy (1980) provided a statistical analysis of all surface and underground coal mine fires reported in the United States from 1950 to 1977. During the latter period, a total of 1,011 fires were reported in underground coal mines of which 15.3 percent were attributed to the belt conveyor. Braun et al. (1981) provided a summary of the failure modes of the 15.3 percent of the total fires attributed to the belt conveyor as shown in Table 1, as follows:

Table 1

Analysis of Causes of Conveyor Fires in the United States
1950-1977

Cause	Number of Fires Per Period									
	1950-1951	1952-1953	1954-1956	1957-1959	1960-1962	1963-1965	1966-1968	1969-1971	1972-1974	1975-1977
Defective rollers	-	-	2	6	13	7	5	6	1	1
Friction between stalled belts & rotating drive drum	-	3	11	6	6	6	4	5	-	-
Electrical arcs	2	2	4	5	1	10	2	3	-	1
Fluid ignition	1	1	5	2	4	3	3	1	2	2
Unknown	1	1	3	1	3	3	-	4	-	2
Total All Causes	4	7	25	20	27	23	14	19	3	6

Litton et al. (1982) also reviewed the McDonald and Pomery statistics and noted that in the period 1960-1969, 67 fires were reported in belt entries and were caused by frictional heating, of which 28 involved the belt drive and 24 involved the belting. In the period 1970-1977, 18 fires were reported of which 10 were of frictional origin and 8 of these involved the belt. Litton et al. (1982) concluded that frictional overheating along the belt is a major origin of fires in conveyor belt haulageways and that the most common scenario for such fires is that of an idler which becomes stuck.

Robinson Dames & Moore considers that the data on conveyor fires in the United States are not directly comparable with data of other countries due to two major regulatory requirements, as follows:

- The entries used for intake and return air courses are separated from conveyor belt haulage entries in which the velocity of the air is limited to that required to provide an adequate supply of oxygen and to ensure that the methane content does not exceed one percent, and such air shall not be used to ventilate active working places.

- An unplanned mine fire extinguished within 30 minutes of discovery does not constitute a reportable accident.

2.2.2 United Kingdom

Cutler and Currie (1979) reviewed statistics of underground fires involving conveyor systems in the United Kingdom in the period 1958-1978, and concluded that approximately 22 fires occur annually which are directly attributable to the operation of conveyors. A further analysis of the data indicated that 87 percent of the fires were caused by four mechanisms: collapsed bearings in rollers; faults on brakes; friction between a stalled belt and a rotating drive drum; and friction between the belt and other items. The most common causes of fires were considered to be collapsed bearings on rollers and faults on brakes.

Statistics of underground conveyor fires in the United Kingdom for the period 1978-1982 were provided by H.M. Chief Inspector of Mines and Quarries in a private communication, and are shown in Table 2. The data in Table 2 indicate that the annual average number of fires on conveyor systems is 24, and that the major causes are defective rollers and faults on brakes.

Table 2

Analysis of Causes of Conveyor Fires in the United Kingdom 1978-1982

Cause	Number of Fires Per Year				
	1978	1979	1980	1981	1982
Defective rollers	7	9	12	15	12
Friction between stalled belt and rotating drive drum	2	-	-	-	-
Faults on brakes	5	6	4	3	-
Faults in gearheads and couplings	-	-	9	-	-
Drive drum revolving in spillage	3	-	-	-	-
Unanalyzed	8	2	3	2	18
Total All Causes	25	17	28	20	30

2.2.3 European Economic Community

Murphy and Neller (1983) reported 472 incidences of fire recorded by European Community Countries in the period 1960-1972 of which 194 (35 percent) affected the belt and, of the latter, 138 (71 percent) were due to frictional heat.

2.2.4 Hungary

Varga (1967) reported the results of an analysis of three Hungarian underground coal mines using a total of 122 belts comprising a total length of approximately 34,000 metres. The total number of fires reported was 43 of which 10 were fires on conveyors and 6 of these were attributed to faulty rollers. Varga considered that all of the fires, detected on belt conveyors, occurred as a result of the evolution of heat by friction and noted the causes of friction as follows:

- Friction between an incorrectly fitted or adjusted roller bush and the cylinder of a roller in the absence of lubricant.
- Jamming of pieces of timber and coal between the top and bottom rollers and at points where the belts touch each other.
- Slippage between the driven-rollers and the belt.
- Friction between the belt and the support structure on the roadway supports.
- Accumulations of coal dust against the belt at the tensioning drums and end cylinders.

2.2.5 Canada

General details of 24 incidents of fires associated with underground coal mine conveyor systems in Canada in the period 1978-1984 were provided in a written communication to Robinson Dames & Moore by the Chief Inspector of Mines, Canadian Department of Labour, Nova Scotia. These incidents are analyzed by primary cause in Table 3.

Table 3

Analysis of Causes of Conveyor Fires in Eastern Canada

Cause	Number of Fires Per Year			
	1978	1979	1983	1984
Defective rollers		1	2	3
Friction between stalled belt and rotating drive drum	2		2	2
Friction between belt and conveyor components or spillage		1	3	4
Faults on brakes	1	1	1	
Faults in gearheads and couplings	—	—	1	—
Total All Causes	3	3	9	9

2.3 RELATIVE FIRE RISKS OF BELT CONVEYOR COMPONENTS

In Robinson Dames & Moore's opinion, the data on the frequency and causes of fires on underground coal mine belt conveyor systems are insufficiently comparable to enable derivation of a ranking of the relative fire risks of the individual conveyor components by statistical analysis. However, the data do permit a ranking by consensus of published information which, in descending order of frequency as a cause of fires on underground conveyor systems, results in the following ranking:

1. Intermediate support structure
2. Drive head
3. Conveyor belting
4. Tail end
5. Tensioning equipment

The major cause of fires on modern belt conveyors is due to the collapse or other failure of the bearings of the idler rollers. The idler rollers are mounted on the intermediate structure of the conveyor and provide a convenient point for the accumulation of fine coal dust either deposited from the belt or carried downstream by the ventilation current

from a loading or transfer point. The risk of coal dust ignition is inversely proportional to the size of the dust and a very fine dust may ignite at a temperature as low as 150°C (Dames & Moore, 1979). Varga (1967) also noted that the danger of fire increases with an increase in the thickness of the layer of deposited coal dust. In the United Kingdom, Thorp (1974) considered that fires initiated by conveyor idlers have generally been caused by bearing failure giving rise to frictional heat as the idler continues to turn, and which eventually ignites coal dust in close proximity to the idler. Braun et al. (1981) identified an alternative scenario in which the idler is jammed due to bearing seizure and the idler drum is frictionally heated by the passage of the belt. As long as the conveyor system continues to operate, the belt will not absorb enough energy during each pass over the jammed roller to ignite. Ignition may occur, however, in the vicinity of the jammed roller when the belt is stopped. An opposite view is taken by the National Coal Board, and Safety in Mines Research Establishment, in the United Kingdom, where the results of a research program enabled the conclusion that the heat generated by a conveyor belt sliding over a stalled roller is not sufficient to cause a fire.

The drive-head components of the conveyor system provide fire risks, of slightly less magnitude and frequency than idler rollers, which result in fires due to:

- Faults on brakes
- Faults on gearheads and couplings
- Friction between a rotating drive drum and a stalled, or partially stalled belt.
- Friction between the belt and coal spillage at the drive head.

Grainger (1984) noted that a prevalent cause of fires associated with belt conveyors is that caused by partial release of the brakes within the drive-head components and the resultant generation of excessive temperatures

which may ignite coal dust deposits or mineral oil residues. Similarly, excessive temperatures may result from mechanical failure within the gearheads and couplings while power remains applied to the motor. Robinson Dames & Moore understands that the latter may have caused, or contributed towards, the conveyor fire which resulted in the closure of No. 26 Colliery in 1984. Friction between the drive drum and the belt, or between the belt and accumulated coal spillage, contribute to the fire risks at the drive head.

Belt friction is a continuing fire hazard and may occur at drive drums when the belt is stalled, or on drum, rollers, and shafts where a strip of belt is being carried round and bearing tightly on another surface, or where the belt is rubbing against structural components of the conveyor, supports and equipment in the roadway, or coal accumulations at the sides of the conveyor, at the tail-end, or at blocked transfer and loading points (Dames & Moore, 1979). Prior to 1950, the fabric construction of the conveyor belt presented a substantial fire risk which has since been largely eradicated by the development of fire-resistant belting.

The tail-end of the conveyor presents a fire risk due to its potential for accumulating fine coal dust carried by the return strand of the conveyor belt and a location where combustible material may become wedged against rollers or belt edges.

The tensioning equipment is the lowest ranked fire risk since there are few recorded instances of fires associated with this component.

3. TECHNOLOGY FOR FIRE PREVENTION AND PROTECTION OF BELT CONVEYORS

3.1 DESIGN OF MECHANICAL COMPONENTS

The design, of the mechanical components of conventional underground belt conveyors, has continued towards the reduction of the fire risks, previously identified in Section 2 of this report, in relation to the relative risks of the various components. The major technical advances are outlined in relation to the applicable conveyor assemblies in the following paragraphs.

3.3.1 Intermediate Structure

The fire risks associated with defective rollers were initially tackled in the United Kingdom by discussions between the National Coal Board and ball-bearing manufacturers which resulted in the production of a special bearing which, on test, was shown to have a four times longer life than the bearings previously installed (Grainger, 1984). To further minimize the risk of fire, the National Coal Board, in conjunction with oil companies, are currently testing idlers lubricated with fire-resistant grease (Grainger, 1984). It is understood that the latter improvement will be introduced in 1985 following a two year development program (Private Communication, 1984). One further development is based on research conducted by the Safety in Mines Research Establishment, United Kingdom, which proved that if a return roller could be "stalled out" when the internal temperature of the bearing reached approximately 120°C, the danger from fire was reduced. The basic principle involved is that a low melting point eutectic is used to hold a locking device in an inactive position. A temperature rise, due to a failed bearing or similar source, results in the alloy melting and releasing the locking device to engage and to stop the rotation of the roller. Research and development is continuing, and temperature-sensitive, self-locking rollers to the National Coal Board design have been manufactured for trial purposes.

Conveyor equipment manufacturers produce various types of intermediate structure which may be floor-mounted, or suspended. The preference in the United States is for suspended structure which provides for ease in cleaning-up spillage. In Robinson Dames & Moore's correspondence with the United Kingdom manufacturers, Dowty Meco Ltd., and Huwood Ltd., preference was expressed for floor mounted structures due to ease of assembly, alignment, reduced spillage, and maintenance. Huwood Ltd. prefers to install its tubular, boltless structure which, it considers, is less conducive to dust accumulations than angle or channel structures, and because the associated idler set has a clamping device which facilitates rapid erection/dismantling of the structure and the adjustment of the idler assembly for tracking the belt. In terms of fire prevention, Huwood Ltd. prefers suspended, garland-type, idlers to obviate the accumulation of material in the idler roller area.

3.1.2 Drive-heads

Grainger (1984) referred to the fire hazards associated with rubbing conveyor brakes and stated that elimination of brakes by the use of sprag clutches and other design improvements are reducing the potential for these incidents. The development and fitting of thermal protection devices to shoe-type brakes provides a warning of the generation of excessive temperatures should a brake malfunction occur.

A further safety factor in relation to braking of loaded conveyors is the power monitoring control system which incorporates a micro-processor to compute the rate of deceleration required to stop the belt and avoids the creation of harsh forces, often associated with early application of brakes to a partially loaded conveyor (Glossop, 1984).

3.1.3 Tensioning Equipment

Most underground conveyors with long centres are now designed with hydraulic, or pneumatically-operated tensioning devices to ensure that the proper amount of belt tension is provided to minimize slippage between the drive and the belt (Traxler, 1980).

3.1.4 Non-standard Conveyors

In conventional, underground coal mine belt conveyors, power is imparted to the belt at a single point and the tensile strength of the belt needs to be rated accordingly. Edwards (1984) referred to the use of linear drives to impart power at intermediate points along the conveyor by the use of short conveyors mounted within the structure of the main conveyor in which frictional contact between the respective strands of the conveyors provides the motive force. Edwards (1984) considered that the system had many advantages including reduced belt tension, lower power requirements, increased length potential, fewer transfer points, greater flexibility in duty and application of power, reduced physical size of components with a high degree of standarization and reduced captial cost. The system may be used to uprate existing conventional installations, in which context it is normally referred to as the "booster drive". Dames & Moore considers that a multiplicity of drives increases the fire risks and that detailed consideration should be given to methods of reducing these risks prior to installation.

Compared with standard underground belt conveyors, the cable belt conveyor offers considerable potential for reduction in fire risks particularly in applications where access to the mine is gained by slopes. Cable belt conveyors achieve high capacity and great lengths by separation of the functions of driving and carrying, relieving the belt of the additional duty of drive transmission that is taken care of by the drive cables which also

support the belt. Where the cable belt drive unit can be located on the surface, Hall (1984) considered that the cable belt offered advantages over the standard multiple conveyor system, as follows:

- Elimination of transfer points and major underground excavations for intermediate drives, tensioning and transfer requirements.
- Elimination of long distance conveyor drive power cables and flameproof switchgear.
- Avoidance of ventilation problems caused by heat generation from intermediate drives in a roadway in which ambient temperatures will be high.
- Installation of the major items of equipment in a properly designed drive house incorporating cranes and maintenance equipment, and allowing ease of access for maintenance.
- Ability to provide a belt washing and drying system to ensure that the conveyor belt is kept clean thus extending the life of the belt and the idlers and eliminating spillage.

3.2 DESIGN OF CONVEYOR BELTING

Prior to 1950, underground belt conveyors involved long lengths of flammable rubber belting used with high-powered friction drives and with other moving parts capable in certain circumstances of generating frictional heating (NCB, 1955). The flammability of the carrier fabric was emphasized by a fire, involving a main conveyor, at Creswell Colliery, England, in 1950, when 80 lives were lost (Atkinson et al., 1959). As a result of the Creswell fire, the National Coal Board proceeded with the development and installation of fire-resistant belting.

The specifications of fire-resistant belting, and the methods of testing vary from country to country as evidenced in Table 4, (Murphy and Neller, 1983).

Table 4

International Fire-Resistant Conveyor Belting Specifications

Country	Spec Number	Flame test	Drum friction	Propane burner	Lab tunnel	Large gallery	Filter test	Cover requirement
INTERNATIONAL	ISO 340	*						
EUROPE								
UK	BS3289/1982	*	*	*				
UK (NCB)	158/1980	*	*	*				
UK (BSC)	As Canada	*	*					*(1)
UK (CEGB)	As Canada	*	*					*(2)
EEC	709/74		*	*				
Belgium	AS/709/74		*	*				
Germany	2ply<1200mm		*	*	*(3)		*	
	Other textile belts		*	*	*(3)	*(4)	*	
France	NFT47108 (1063)	*						
	also 709/74		*	*				
Poland	PN76-D04030	*	*			*		
Romania	STAS8893-71	*						
Czechoslovakia	CSN260370	*	*					
AMERICA								
USA	MSHA30-CFR18-65	*						
Canada	EMR1C215FRL269	*	*					
ASIA	IS3181 (1966)	*	*					
India								
Japan	JISK6324 (1966)	*						
AUSTRALIA								
Australia	AS1334 (1982)	*	*					
AFRICA								
South Africa	SABS971 (1980)	*	*					

* indicates requirement

(1) cover tensile strength N15

(2) cover tensile strength N17

(3) Din22118

(4) carried out at Tremonia

3.2.1 Flame Testing

Table 4 indicates that the majority of countries use a flame test and a comparison of the principal methods and acceptance criteria is provided in Table 5 (Braun et al., 1981). The inadequacy of small-scale belt fire tests has been demonstrated (Mitchell et al., 1967, Warner, 1975) by the capability of certain "approved" belts of neoprene and polyvinylchloride construction to propagate flame over their entire length when full-scale fire conditions were simulated (Sapko et al., 1981). Similar results in Germany and Poland revealed a lack of correlation between results of small sample flame testing and large gallery burning tests and resulted in the exclusion of the flame test (Murphy and Neller, 1983). In Germany, large gallery burning tests are required for all belts for underground use in excess of 2-ply, 1200 millimetres wide, where 20 metres of full width belting is ignited with 300 kilograms of wood in a typical mine roadway in an air current of 1.2 metres per second. Approval is given if 5 metres of the belt remains intact when all burning has ceased. Similar testing is conducted in Poland but requires 20 metres of the original 60 metres of the tested belt to remain intact (Murphy and Neller, 1983).

The European Economic Community has accepted standardisation of testing for fire-resistant conveyor belting where the British drum friction test and a propane burner test developed in Holland and Belgium are recommended for type approval purposes. The propane burner test has been found to be particularly useful in confirming the acceptability of new construction of belts (Makower and Saunders, 1979). The test is carried out in a gallery of square section 2 metres x 2 metres, through which air is drawn at an average velocity of 1.5 metres per second. A full width rectangular sample of belting 2 metres long is mounted on a trestle. The sample is subjected to a flame from a burner which is supplied with a total of 1.3 kilograms of propane over a period of ten minutes. The burner consists of a 450-millimetre square frame having an overall height of 220 millimetres; it is made of welded steel tubing with an external diameter of 20 to 25 millimetres. The tubes, four longitudinal and two lateral, contain a total of

Table 5

Flame Test for Conveyor Belt Qualification for Underground Coal Mines

Test Method / Specifications	ISO-R340 / Germany DIN 22 103	British BS 3289	MSHA 30 CFR Part 18	BCC Propane Grill Test	Germany DIN 22 118
Specimen Size (Wxl)	25mm x 200mm	25mm x 305mm	13mm x 152mm	"Normal" x 4M	90mm x 1.2M
Number of Specimens Tested	12		4	2	1
Specimen Orientation (Longest Axis)	Vertical	Horizontal	Horizontal	Horizontal	Horizontal
Burner Type	Spirit Burner	Barthel-Spirit Burner	Bunsen Burner	450mm Sq. Frame 52 Jet	Fremke Bunner (Similar to Bunsen)
Fuel	95% Ethanol 5% Methanol	90% Propane 10% Propane	95% Ethanol	Propane	Natural Gas
Flame Length	150-180mm	152mm	76mm	(.13 Kg/min)*	10mm
Exposure Time	45 sec.	30 sec.	60 sec.	10 min.	15 min.
Specimen Distance Above Burner	50mm	51mm	25.4mm	130mm	40mm
Chamber Airflow Rate	1.5 M/s (60 sec. After Exposure)		1.5 M/s (After Test Exposure)	1.5 M/s (After Test Exposure)	.5 M/s (During Test Exposure
Direction of Airflow	Normal to Flame Spread		Parallel to Flame Spread	Parallel to Flame Spread	Parallel to Flame Spread
Acceptance Criteria	Afterflame Time: <45 sec. Avg. <15 sec. Each	Afterflame and Glow: <3 sec.	Afterflame: <1 min. Afterglow: <3 min.	Self-Extinguish With a Portion of Sample Intact Across Entire Width	Self-Extinguish With a 40cm Section to Remain Intact

* Specifies mass consumption rate rather than flame length.

52 holes through which flames impinge on the belt sample. The test requirements are that the belting shall be self-extinguishing after the propane flame has been removed and that at least a 250-millimetre length of the test piece shall remain undamaged at the end of the test after all combustion has ceased.

3.2.2 Drum Friction Test

Table 4 indicates that the majority of countries use a drum friction test to measure the resistance of the belt to ignition by frictional heat and a comparison of the principal methods and acceptance criteria is provided in Table 6 (Braun et al., 1981). The European Economic Community has standarized on the British drum friction test in which a 150-millimetre wide sample of belt is passed through an arc of 180 degrees around a steel drum with its axis horizontal, one end being secured and the other attached to a tensioning system so that an initial tension of 343 newtons (which may be increased by stages to 1715 newtons if the belt does not break during the test) is applied. The drum is rotated at 200 revolutions per minute. Three tests are carried out in still air and three with an air current over the belt. The criteria for passing the tests in the United Kingdom are (Makower and Saunders, 1979):

- There shall be no visible signs of flame or glow on any part of any one of the six test pieces either during the test or after each test piece breaks;
- The temperature measurement of the surface of the drum shall not exceed 325 degrees Celsius.

The latter criterion is amended to 500 degrees Celsius for belts having polychloropene covers. Pearse (1984) reported the development of a range of non-flammable belts, complying with NCB and worldwide specifications, and having polychloropene covers on a PVC impregnated carcase.

Table 6

Specifications of Various Drum Friction Tests

Specifications	European Community Countries		South Africa		National Coal Board		U.S. Bureau of Mines	
Specimen Size (WxL)	150mm x 1M		225mm x 1.5M		152mm x 4.6M		229mm x 1.5M	
Number of Specimens Tested	6		2		2		1	
Drum Size (DIA)	Steel - 210mm		Steel - 450mm		Steel - 203mm		Steel - 457mm	
Initial Drum Temperature	<30° C		—		—		—	
Drum RPM	190		110		190		110	
Air Velocity	120M/min		90M/min		152M/min		91M/min	
Minimum Initial Air Temperature	5° C		—		—		—	
Maximum Ventilation Rate of Test Room	<30M/min		—		—		—	
	Kg	min	Kg	min	Kg	min	Kg	min
Total Load on Belt	35 70 105 140 175	60 30 30 10 Fails	22.5 34 45.5 59.5 75.5 91.5 107.5 123.5	15 15 15 15 15 15 15 15	32 68 105 141 177	120 10 10 10 Fails	22.5 34 45.5 59.5 75.5 91.5 107.5 123.5	15 15 15 15 15 15 15 15
Acceptance Criteria	No Flame or Glow		No Flame or Glow		1) No Flame or Glow 2) Max. Drum Temp. <300° C		1) No Flame or Glow 2) Max. Drum Temp. <250° C	
Comments	Test 3 w/air 3 w/o air		Reverse Specimen Surface		Test 1 w/air 1 w/o air			

3.2.3 Quality Control

Makower and Saunders (1979) reported that the United Kingdom was the only country which had consistently applied quality control to deliveries of belting by subjecting a sample of 25 percent of all consignments to the Barthel burner flame test. Since that time, the EEC countries have been giving extended trials of quality control procedures using both the Barthel burner flame test and the critical oxygen index test. In the latter test, a sample 50 millimetres wide and 70-150 millimetres long, from the full thickness of the conveyor belting, is held vertically in a frame and is ignited by a gas flame in an atmosphere of oxygen and nitrogen, the igniter is then withdrawn. The critical oxygen index is the minimum concentration of oxygen, expressed as volume per cent, in a mixture of oxygen and nitrogen that will just support flaming combustion of the sample. Combustion is regarded as having been sustained if the specimen continues to burn for 3 minutes after withdrawal of the igniter.

3.2.4 Fume Tests

Murphy and Neller (1983) reported that Germany was the only country with a preference for a fume extraction test, the Bissen filter test. It is understood that the latter test is designed to determine the toxicity and thermal oxidative degradation characteristics of the ingredients employed in the formulation and manufacture of conveyor belts and is similar to research conducted by the U.S. Bureau of Mines (Hartstein and Forshey, 1976, Christos et al, 1977). The latter research indicated that styrene-butadiene rubber reinforced with Dacron fiber, or the aromatic phosphate esters of the flame-retardant plasticizers studied, offer the least toxic hazard. Silvey (1982) showed that the major fire-resistant conveyor belt products had cover compounds of the constituent parts as follows:

(1) Styrene butadiene rubber, or SBR plus Hycar® blend	100
(2) Carbon black and mineral filler	80
(3) Chlorinated petroleum resin	30
(4) Fire-retardant additives, (metallic borates, antimony oxide, phosphate)	15
(5) Liquid plasticizers	10
(6) Internal lubricants to lower friction	15
(7) Protective chemicals	5
(8) Curatives	10
	255

3.2.5 Other Requirements

Murphy and Neller (1983) reported that, in addition to the international fire resistance specifications, some end users such as the British Steel Corporation and the Central Electricity Generating Board in the United Kingdom specify a cover of a particular tensile strength. The latter end users are required to comply with the Canadian Department of Mines specification to meet the cover tensile of N.15 or N.17.

3.2.6 Developments in Test Procedures

Murphy and Neller (1983) reported that work is in progress to further evaluate flame-resistance testing as related to underground conditions since, at present, all tunnel and gallery tests are carried out in a horizontal plane. Evaluations are taking place on an inclined gallery (Germany) and on inclined propane burner tests (Belgium). In the United Kingdom, the National Coal Board has introduced the extended propane burner test for new product development and high strength belting which evaluates the fire resistance after sustained burning of the sample.

3.2.7 Joining Belts

Pearse (1984) noted that belts may be joined by mechanical fasteners or by vulcanizing. Mechanical fasteners are preferred when belts require frequent extension or shortening; when they frequently need to have sections replaced or repaired; when the splicing operation has to be carried out in a

short time or under adverse conditions; or when the skilled operators and special equipment for vulcanizing cannot be readily obtained. The current trend in mechanical fasteners is towards the hinged hook, staple, or rivet fasteners which have less tendency to reduce the tensile strength of the belt than bolted types of fasteners. Vulcanization is preferred for joints on major conveyor belts and should be used in accordance with manufacturers' stipulated methods to be used for each belt type.

3.2.8 Steel Cord Belting

The use of steel cords as a tension carrying member in conveyor belts enables very large powers to be applied on long distance and/or steep incline single flight conveyors (Edwards, 1984). In Robinson Dames & Moore's opinion, the use of steel cord belting may reduce fire risks compared with standard belting by permitting the elimination of transfer points and associated intermediate drives in the conveyor system. Pinnington and Lancaster (1984) considered that the main advantage of steel cord belting may be its joint efficiency and the fact that properly made joints never tend to open up and strip back, as with textile belts. The joint efficiency permits the belt to be worked at a lower factor of safety than conventional belts. Grainger (1984) considered that steel cord belting is competitive with cable belt equipment for long distance conveying and cited, as an example, that the second belt at Gascoigne Wood, within the Selby Mine Complex, is of steel cord construction and has an identical capacity to the cable belt conveyor originally installed.

3.2.9 Summary

The introduction of fire-resistant conveyor belting to underground coal mines has substantially reduced the fire hazard due to the combustibility of the conveyor belt. Specifications for fire-resistant conveyor belt, and the tests required, vary from country to country but the European Economic Community appear to have reached a measure of standardization in tests which are more exacting than those used, for example, in Canada and the United

States. In particular, the small sample flame test has been shown to provide results adversely at variance with large gallery tests and reliance on the former may result in the use of conveyor belting which has a lesser degree of fire resistance than could otherwise be available.

3.3 FIRE-RESISTANT HYDRAULIC FLUIDS AND GREASES

The involvement of oil or grease in mine fires is a reflection of the number of fires started by frictional heatings on mechanical equipment. Mineral oils present the greatest hazard. While fire-resistant fluids are available as substitutes in hydrostatic and hydrodynamic applications, mineral oils still find extensive usage for lubrication purposes (Dames & Moore, 1979).

Ladov and Law (1978) and Law (1980) described the development and testing of an advanced water-in-oil emulsion for underground mine services. The emulsion was of the class HS-B as defined within the four classes of fire-resistant hydraulic fluids recognized by the International Standards organization, shown in Table 7, as follows:

Table 7

ISO Fire-Resistant Hydraulic Fluid Classifications

Class	Description
HS-A.....	Oil-in-water emulsions containing a maximum of 20 % combustible material. These usually contain 95 % water.
HS-B.....	Water-in-oil emulsions containing a maximum of 60 % combustible material. These usually contain 40 to 45 % water.
HS-C.....	Water-glycol solutions. These usually contain at least 35 % water.
HS-D.....	Water-free fluids. These usually refer to phosphate ester-containing fluids.

Law (1980) noted that several spray ignition test procedures, all designed to simulate the introduction of a possible ignition source on a hydraulic fluid spray caused by fracture of a high-pressure pipe or hose,

are used by test laboratories in Canada, United States, or Europe. All of these tests are based on the same general principle of spraying a pre-heated fluid through a defined nozzle at specific temperatures and pressures, but differ from each other with respect to operating conditions, ignition source, and observations recorded. Those tests widely accepted for the evaluation of HS-B fluids are shown in Table 8, as follows:

Table 8

Spray Flammability Tests and Test Results

Test Method	Country	HS-B Water Content Required For Passing Results, % wt*
MSHA Title 30, Part 35	USA	40-45
Factory Mutual Standard 6930	USA	40-45
Energy Mines and Resources	Canada	40-45
United Kingdom National Coal Board	UK	30-35
Luxembourg V Report	Europe	> 50

*Assuming continuous phase 20 cSt paraffinic oil, no additional chemical flame retardant.

Law (1980) concluded that more work is needed to develop new spray flammability tests with improved precisions, as well as documented relevance and correlation with service hazards. However, Law further concluded that the fire-resistance of water-in-oil emulsions, even accepting the range of pass/fail criteria, is very much greater than that of mineral oil fluids used conventionally in the same equipment.

Thorp (1974) noted that, in British coal mines, the majority of traction-type fluid couplings are water filled, and that scoop couplings mainly use non-toxic phosphate ester.

Thorp (1974) noted also that there was no fire-resistant grease. As a result of a private communication, it is understood that, following a two year development program, the use of fire-resistant greases in belt conveyor idler and return rollers will be introduced by a manufacturer in 1985 in the United Kingdom.

3.4 ANCILLARY EQUIPMENT

Equipment ancillary to the belt conveyor which contributes to fire prevention and protection comprises loading and transfer point chutes, and belt cleaning devices. The literature on chutes is sparse but the design considerations provided by the Committee on Roadway Conveyors, (National Coal Board, 1955) may be considered to remain valid and the text of these is provided in Appendix 3. All chutes should incorporate a sensing device to detect a blockage in the chute and to stop the conveyor in order to prevent the potential ignition due to belt friction. McCarthy, (1965) described four blocked chute devices comprising:

- a pivoted paddle
- a tight wire
- ultrasonic beam or photoelectric cell
- vibrating reed

In most cases, the piling-up of material in the chute is sufficient to cause a mechanical action, or interruption of a beam, which causes a feed relay to de-energize and to open the motor feed circuit. Chute blockage, caused by large lumps of mineral, particularly where hard strata materials form a significant part of the conveyor load, may be minimized by the introduction of mineral sizers into the conveyor system at suitable points (Watt, 1984).

Belt cleaning devices are required to minimize the carrying-back of fine material which becomes deposited on the conveyor structure adjacent to the idler rollers and creates a fire hazard. Stahura (1984) considered that

cleaning equipment should be considered before the conveyor's structure is designed and fabricated in order to ensure that installation space is made available and to optimize cleaner performance. Rappen (1984) considered that belt scraping devices based on intermittent linear contact by means of individually adjustable and, in some cases, spring-loaded scraper blades, usually of metallic construction, have established themselves in the market as the most advanced types of belt cleaner. Rappen (1984) also considered that a universally mounted plough scraper was required on high performance belts to clean the lower strand.

3.5 PROTECTIVE SENSING DEVICES

Fire risks of the drive-head components of underground coal mine conveyors may result from one or more of the following:

- Excessive belt slippage between the driven rollers and the belt.
- Excessive friction due to belt misalignment.
- Excessive temperatures due to sticky brakes, or bearing failures.
- Continued operation of conveyors inbye of a stopped conveyor in a sequential system resulting in excessive spillage, potential overloading, and friction between the belt and spillage.

All components of the conveyor may incur fire risks associated with a torn belt which may become jammed and give rise to excessive frictional heating.

Belt protective sensing devices are utilized to detect the potential causes associated with the fire risks identified above and were generally described by McCarthy (1965), as stated in the following paragraphs.

3.5.1 Belt Slippage

Belt slippage, in excess of normal, may occur due to incorrect tensioning of the belt through the loop take-up belt tensioning system, and due to belt overloading or jamming. The level of belt tension is normally determined by design and can be pre-set and subsequently monitored by a dynamometer. Where the loop carriage is controlled by an electric winch, the belt tension can be controlled either manually or automatically and limit switches are incorporated to detect when the loop take-up carriage is at its extremes of travel. Belt slippage due to overload or jamming of the belt can be detected by a belt-speed sensitive switch. The switch is pre-set at a proportion of the nominal belt speed and reacts when the belt speed drops below the pre-set value while the conveyor drive is operating at full speed.

3.5.2 Belt Alignment

The safe and efficient operation of the belt is dependent on its movement along a center line in the direction of travel. Excessive deviation from the center line for prolonged periods may result in frictional heating, spillage, and belt damage. Misalignment of the belt can be detected by mechanical switch devices, fitted with heavy duty rollers, positioned at either side of the conveyor at those points where belt misalignment would have the most adverse effect. The rollers are spring-loaded to ensure their return to the control position after re-alignment of the belt is effected.

3.5.3 Temperature

Excessive temperatures may occur due to faulty brake operation, or due to mechanical or electrical breakdown in the gearboxes, at the drive head, and are normally detected by temperature probes. Brake drum temperature probes provide a means of monitoring mal-adjustment such as trailing brake shoes and monitoring devices may additionally check and monitor brake

operation i.e. brake on, brake off, and brake wear. Additional devices are required to detect the operating relationship if a brake and sprag combination is adopted on inclined conveyors. An alternative to the brake and sprag combination is the use of a torque responsive brake which ensures that the motor drive takes the load before the brake is released.

Bearing temperatures are currently accepted as a means of monitoring the stability of a conveyor drive and may be augmented by monitoring the gearbox oil level and temperature. Thermistor probes are fitted in key bearing housings and in a thermowell, which intrudes into the oil reservoir of the gearbox splash lubrication system. Set points are established at slightly above in-situ operating temperatures and, thereafter, temperature probes monitor temperature rise.

3.5.4 Torn Belt

During conveyor operation, the edges of a belt can become damaged to the extent that belt trailers develop and which may become jammed in moving parts and provide a source of frictional heating or severe damage to the belt. Detection of torn belt is made by the fitting of sensitive limit switches to a wire or bar suspended from side to side under the belt and generally following the troughing contour. The switches are operated by any strip of torn belt hanging below the surface of the belt which strikes the wire or bar.

3.5.5 Sequence Control

An underground coal mine conveyor system may consist of a number of individual conveyors transporting mineral from inbye to outbye in sequence. The continued operation of conveyors inbye of a stopped conveyor in a sequential system may result in excessive spillage, overloading at the tail-end of the stopped conveyor, and friction between the operating belt and the accumulating spillage. Sequence control of conveyors was introduced both to minimize the foregoing hazards and to effect the introduction of

manless transfer points. Conveyor sequence control is provided by means of a belt drive generator or centrifugal switch, such that when the outbye belt is run up to speed, the contacts close and enable the next inbye conveyor to start. Conversely, when the outbye conveyor is stopped, the contacts open and stop the following conveyor.

3.6 CONVEYOR SELECTION AND INSTALLATION

The selection of a conveyor adequate for the ultimate duty that it is required to perform is of considerable importance in the reduction of fire hazards associated with belt conveyors in underground coal mines. The National Coal Board (1951) established methods of conveyor selection to avoid such errors in selection as:

(a) Using a belt which is too small or too slow to carry its load without undue spillage (in this connection it is very important that, where large lumps of coal have to be conveyed, proper allowance should be made for them when calculating the size of belt needed).

(b) Using belting on drums of unsuitable diameter.

(c) Installing a motor which will frequently be overloaded.

(d) Installing too powerful a motor which may cause damage to the belting or the joints.

(e) Extending a belt to such a distance that there is undue risk of breakdown.

The methods and criteria for conveyor selection are well published in the literature and considerable assistance is available from conveyor manufacturers. However, in underground coal mines, it is seldom sufficient to consider any one conveyor in isolation since it is the overall coal clearance system which is of fundamental importance. In the latter regard, Watt (1984) considered that a coal clearance system should:

- Provide continuous clearance from the point of production to the surface with high levels of reliability and safety, at the rate required by the producing unit.

- Meet substantial variations of this rate, particularly for relatively short production peaks.
- Be economical in manpower and cost and capable of remote control or automation.

To facilitate consideration of the requirements of the coal clearance system and selection of conveyors of adequate duty, the National Coal Board's Operational Research Executive developed computer programs which permit the simulation of conveyor systems under specified clearance demands and constraints. The computer program was described by Price and Szabo (1970) who considered that the programs had proved extremely useful for planning complicated conveyor and bunker systems for the future.

In its consideration of conveyor belt installations, the Committee on Roadway Conveyors (National Coal Board, 1955) concluded as follows:

- Conveyor installations should be carefully planned in advance in the light of all the circumstances underground; loading and transfer point arrangements should be planned in detail and attention should be given to chutes, illumination, dust suppression measures, control and signals.
- Roads should be straight with accurately set supports. Adequate clearances under, above and on both sides of the conveyor should be provided. There should at least be a 30-centimetre clearance under the conveyor. The effects of later ground movement will be counteracted most easily by the use of adjustable legs to support the conveyor or by slinging it from the roof.
- Transfer and loading points should be designed in detail and not left to improvisation.
- Conveyor installation should be set to a high standard in respect of level, alignment, clearances, and cleanliness.

Associated with alignment, Robinson Dames & Moore has noted the use of laser beams to preserve alignment on major installations. Archibald (1974) referred to the installation of a cable belt at the Longannet Mine Complex, Scotland, and noted that at all changes of gradient the mine had been driven

on vertical curves specified by the conveyor manufacturer. Traxler (1980) also noted, in respect of conveyor installations, that sufficient vertical curve radii are important for good conveyor operation and good belt life.

In the United Kingdom, a National Coal Board instruction of 1953 required all conveyor belt transfer and loading points to be of fireproof construction. Additionally, the United Kingdom Mines and Quarries Act, 1954, requires that any area of the mine served by a single intake shall require the intake to be constructed or treated to be, as far as can be reasonably foreseen, free from the risk of fire.

Thorp (1974) separated the fuels that can be encountered underground into two categories as follows:

- Indigenous materials naturally present in the mine including methane, coal and coal dust, and, occasionally, oil.
- Materials imported into the mine including timber, paper, flammable fluids and greases, and plastics.

Roberts (1969) described the fire risks associated with timber that had not been treated with a fire-retardant, and the Auchengeich Colliery fire (1959) showed that intolerable conditions may result if untreated timber is ignited by a powerful source of heat such as that provided by a fire in a substantial quantity of mineral oil.

There is virtually only one impregnated fire-retardant treatment for timber in the United Kingdom which is known as "Fyreprufe" and which was developed by Williams (1966). The mixture used for impregnation consists of:

Ammonium sulphate	89 percent
Monammonium phosphate	5 percent
Sodium fluoride	4 percent
Sodium chromate	2 percent

Pressure impregnation is carried out to achieve an average salt loading of not less than 43 kilograms per cubic metre for hardwoods and 50 kilograms per cubic metre for softwoods. Makower and Saunders (1979) noted, in relation to the fire-retardant properties of coverboards treated with Fyreprufe, that the properties were retained for periods up to 12 years underground.

Wilde (1972) discussed the development of fire-retardant surface coatings for application to rock, coal, timber, or other exposed surface, and concluded that those based on sodium silicate can be effective but are difficult to apply. Since 1972, commercial sealant coatings have been developed and include Camlit, Cemet Seal, Gypseal, Hardstop, and Mandoseal (National Coal Board, 1968). Legislation in the United Kingdom forbids the use of polyurethane foam as a sealant underground and Wilde (1972) showed that flames spread over the surface of polyurethane foam approximately 100 times faster than flames spread over non-impregnated coverboards.

In Robinson Dames & Moore's opinion, further consideration should be given to effecting a reduction in the use of timber in main arterial roadways, particularly for cribbing above arch girders which, in the event of fire, may result in the domino-type collapse of the arches and closure of the roadway.

In Canadian and European coal mines it is common practice for conveyors to be installed on the main intake airways. This means that, not only is the system antitropal, with airborne dust carried towards the working faces, but fire caused by a conveyor will tend to travel towards the face and render part of the roadway unuseable as an escape route. In addition, the smoke and fumes are carried to the working faces and the return airways, cutting off the remaining escape roads.

There are two arguments for the practice of placing main belts in the intake. The first is that, if the conveyor is a fire hazard, it should not be in the return air carrying methane from the mine. This argument is

debatable unless the mine is subject to outbursts or heavy methane emission rates. The second argument is that the face electrical switchgear is often on the conveyor road so that it too would then be in the return. Alternatively, to put the trunk conveyor in the return and the district conveyor in the intake would mean passing coal through doors, creating another dust problem as well as leakage.

It is suggested that these objections can be overcome by adaptations of the layout shown in Figure 1, (Dames & Moore, 1982).

3.7 MAINTENANCE

The Committee on Roadway Conveyors (National Coal Board, 1955) considered that maintenance is probably the biggest single factor in safe and efficient conveying and that maintenance problems are increased where conveyors are not well suited to their work or are insufficiently installed. The Committee concluded as follows:

> Every possible effort should be made to raise standards of conveyor maintenance to a high level; schemes of routine examination and testing of machinery called for under the Coal Mines (Mechanics and Electricians) General Regulations, 1954, should be carefully worked out to suit the local circumstances of individual conveying installations; attention should be paid to the proper recording of examinations, repairs and renewals. The schemes should provide for regular inspections and should be designed:--
>
> (i) to set and preserve a high standard of installation, including level, alignment, clearances and cleanliness; and
>
> (ii) to detect at an early stage and to rectify deterioration of component parts of the conveyor system through wear and corrosion.
>
> Different elements of the conveyor will call for treatment and examination at different intervals. Maintenance of the electrical components should form part of the general scheme of maintenance of electrical equipment in the mine.

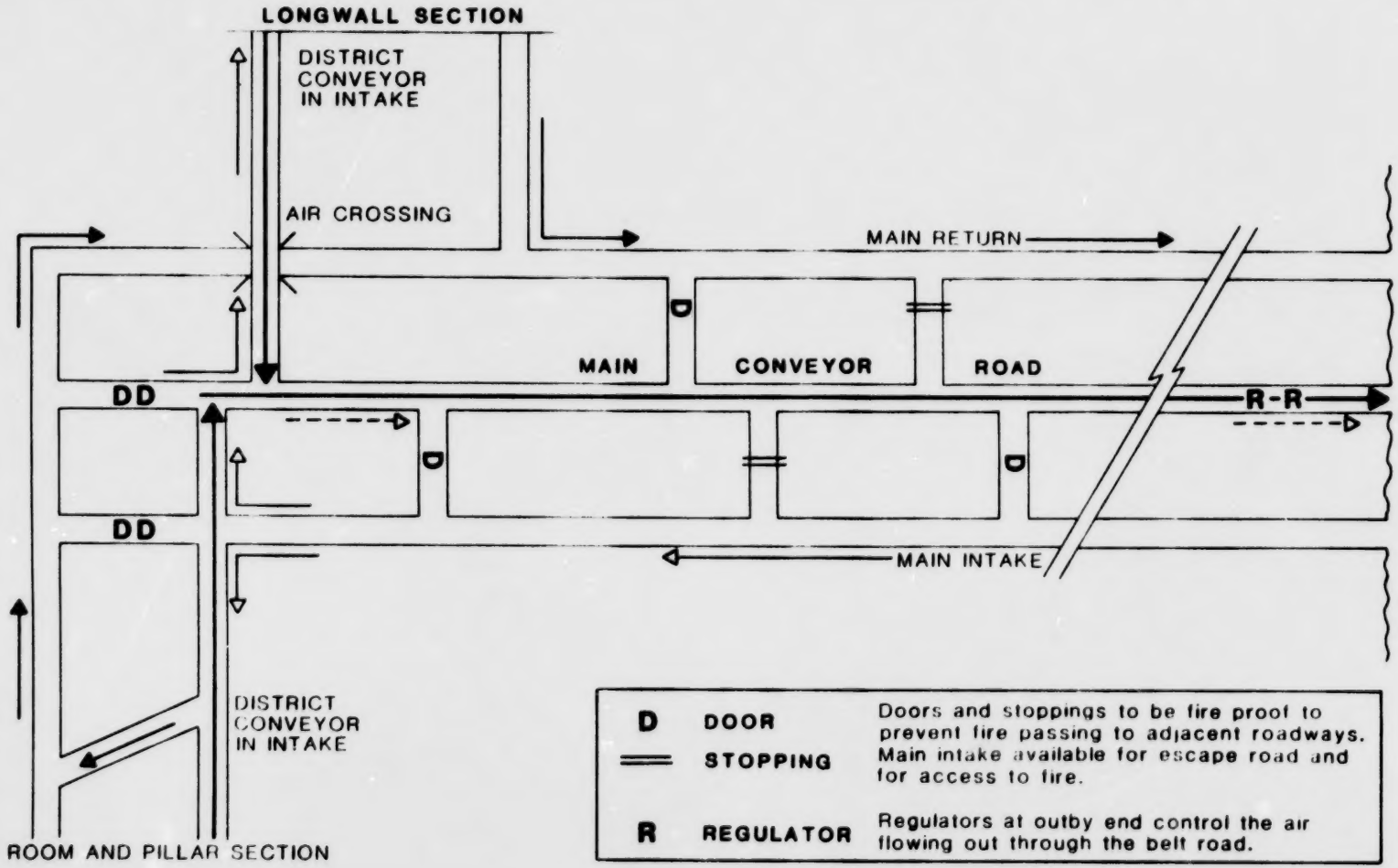


FIGURE 1 - VENTILATION OF MAIN CONVEYOR ROADS

Varga (1967) considered that regular and continuous repair and maintenance, especially careful checking of the transport of lumps with dimensions exceeding the permissable size, and efficient inspection personnel, not only increase the reliability and long working life of the belt equipment, but also represent the principal measures for the prevention of the formation of points of fire danger. In respect of the fire hazards associated with idler rollers, Varga considered that the method of protection consisted in systematic preventative maintenance and repair, carried out sufficiently carefully and regularly.

Thorpe (1974) considered, particularly in relation to belt conveyor systems, that mechanical and electrical equipment for use in underground coal mining should be so designed, engineered and installed to reduce to a minimum the risk of fire and, after installation, that it cannot be overemphasized that it is absolutely essential for the equipment to be regularly inspected and properly maintained.

Warner (1975) stressed the importance of maintenance in fire protection and considered that fire detection systems should be tested following installation and periodically thereafter on a regular, routine basis. Warner (1975) further considered that fire extinguishing systems should be also checked periodically as follows:

> "The flow rates of water deluge and automatic sprinkler systems should be checked to be sure that adequate water pressure is available, and that the water lines have not become obstructed over a period of time by corrosion or sediment, or simply by the entrance of foreign objects into the system. Dry chemical systems should be discharged periodically. Foam systems should be operated periodically to be sure that they are in an operable condition. Frequent visual inspections are important to detect any obvious damage or malfunctions that would result from the day to day operations in the mine."

Factory Mutual Engineering Corporation (1977) considered that maintenance procedures to prevent conveyor fires should include the following:

- Regular inspection of belt conveyors during operation to detect any belt slippage, defective rollers, or incipient fire.
- Adequate lubrication of motors and other moving parts.
- Removal of any accumulations of spilled conveyed material that may provide fuel for a fire or jam a roller.
- Maintenance of lubrication systems in good repair to avoid excessive leakage.
- Regular inspection of wiring for damage where exposed.

4. TECHNOLOGY FOR FIRE DETECTION

4.1 OBJECTIVES AND PRINCIPLES

In underground coal mines, a developing fire poses a significant hazard. The purpose of a fire detection system is to provide a warning of this developing hazard in a time-frame sufficient to successfully initiate evacuation and control measures (Litton, 1981).

Fire detection is based on the principles that a fire causes a change in the ambient conditions in some detectable quantity and that there is a means of detecting the presence of some fire-produced quantity (Litton, 1981). Griffin (1979) characterized any product of a fire that changes the ambient conditions as a fire signature and considered that the principal fire signatures, detectable by available sensors, were aerosols, energy and gases. Aerosols are particles suspended in air as a result of the process of combustion which releases large quantities of solid and liquid particles in a size range of 5×10^{-3} to 50 um into the air. Sub-micrometer particles are referred to as products of combustion, are invisible, and are, in most cases, the earliest appearing fire signature. Particles larger than 0.3 um are visible usually as smoke. Energy fire signatures are represented by heat and light in terms of increases in air temperature, infrared emissions, and ultraviolet emissions resulting from flames. As a result of combustion, gases are added to the atmosphere of which the principal gas, present in almost all fire situations, is carbon monoxide (CO). Slow-burning and fuel-rich fires, in particular, produce large quantities of CO.

The detection of fires by sensors is possible for changes in ambient conditions represented generally by smoke, rise in temperature, radiation energy, gaseous emission, and sub-micrometer particulate emission.

4.2 FIRE DETECTION BY SENSORS

4.2.1 Smoke

Smoke may be detected by photoelectric or ionization-type sensors. The requirements for photoelectric sensors are a source of light and a detector of that light to measure its radiant power. The commercially available units for mine use are usually of the light-scattering type in which smoke, entering a chamber, scatters the light from its source and changes the resistance of a photocell which causes an alarm. Griffin (1979) noted that photoelectric sensors required periodic cleaning in dusty, mine atmospheres, were dependent on airflow velocity, and were less sensitive to black smoke than to white or grayish smoke. Litton and Herzberg (1977) considered that photoelectric sensors were capable of detecting particles of combustion but that their sensitivities were so low that dense smoke clouds must be present before they respond.

Ionization-type smoke detectors are based on the principle that combustion particles, entering a chamber in which a minute electric current passes through ionized air, cause the current to drop. The Becon MK II detector is used extensively in mines in South Africa (van der Walt, 1976), and has a single ionization chamber open to the mine atmosphere. Ionization is effected by the radio-active gas, Krypton 85, and a direct current of 10 volts, applied between the electrode and the chamber, generates a current of 10^{-9} amps. The detector is sensitive to variations in ventilation air velocities and to atmosphere pressure. Van der Walt (1977) reported that the Becon MK II detector, when used in conjunction with a CO_2 gas sensor, had never failed to respond to a fire.

In the United Kingdom, Miller (1981) reported the use of the Trolex P3270 smoke detector which is an ionization-type sensor in which two radioactive sources are mounted, one in a sealed chamber and the other in a chamber open to the atmosphere. Miller (1981) noted that, in its basic

form, the P3270 smoke detector is only suitable for use in air velocities up to 3 metres per second and that its performance is affected by the constituent parts of a fire and its siting.

4.2.2 Temperature

Thermal sensors detect an increase in air temperature and actuate an alarm that signals the presence of a fire condition. Actuation of a thermal sensor may be electrical or pneumatic. In the category of electrical actuation, thermocouples are the most widely used and rely upon a bimetallic junction which generates an electromagnetic force when heated. Thermoresistive types of heat sensors, such as resistance thermometers and thermistors, respond to temperature increases by a change in resistance, but sensitivity and reliability are affected by changes in ventilation flow and humidity (Litton, 1979). Other types of thermal sensors include (1) fixed temperature sensors made of temperature-sensitive materials, which expand, bend, or fuse to produce an alarm; (2) rate-of-temperature rise sensors, which respond to increasing temperature changes; (3) line-type heat sensors, which produce an alarm when heated; and (4) pressurized, heat-sensitive plastic tubes, which melt at a given temperature resulting in a loss in pressure.

Fixed temperature, and rate-of-temperature rise, sensors are categorized as thermal point type detectors in terms that they are located at fixed points in relation to the belt conveyor installation. In the United States, under The Code of Federal Regulations, Title, 30, Mineral Resources, thermal point type detectors or other detectors providing equivalent protection, are required to be installed at the beginning and end of each belt flight, at the belt drive, and at incremental distances not exceeding 38 metres along each belt flight. Fixed temperature sensors are localized temperature sensors and suffer from the additional constraint that a specific temperature must be reached before an alarm can be actuated (Litton, 1979). Warner (1975) recommended that the fixed temperature detector rating should be between 57°C and 74°C where the ambient

temperature does not exceed 38°C, and between 79°C and 107°C where maximum ambient temperatures are between 38°C and 66°C. Rate-of-temperature rise detectors are designed to respond to changes in temperature at a rate of approximately 8°C per minute. Griffin (1979) considered that the latter sensors were not suitable for the detection of smouldering fires, although Litton (1979) stated that some sensors of this type have built-in compensation for the rate-of-temperature change and offer some capability for use in the detection of small, or slowly developing fires.

In the United Kingdom, Miller (1981) reported the development of the BTH1 Temperature and Humidity Monitor MRD 74494 in which the temperature is detected by a thermilinear thermistor assembly. The instrument measures temperature in the range of 0 to 45°C in 5°C increments.

Thermal continuous, or line-type, detectors provide good resistance to the mine environment, and most provide good sensitivity to belt fires (Warner, 1975). They are more versatile than point-type heat sensors because they form a continuous heat sensor over the entire area to be covered (Litton, 1979). The line or wire types use thermistor material, eutectic salt, pressurized gas, or twisted, insulated wire under tension as a source of detection (Griffin, 1979).

A further type of continuous detector is provided by heat-sensitive plastic tubes which are pressurized by air. An increase in temperature melts the tubing, resulting in a loss of pressure. The pressure loss is sensed and an alarm is actuated. Stitt (1977) described the Air-Lert system in which thermoplastic hose is suspended from the roof along belt conveyor entries. The hose is pressurized with air at between 207 and 345 kPa and, in the event of fire, the temperature rise causes the base to soften and ultimately rupture at 77°C. The rupture causes a complete loss of air pressure which produces a visible and audible alarm signal via a low-pressure switch in a master control unit, normally located at the belt head.

4.2.3 Radiation

The occurrence of a fire causes the release of energy in the form of electromagnetic radiation which may be selective molecular radiation or graybody continuous radiation. Selective radiation occurs when gaseous species within the flame, which have been initially excited to higher energy levels owing to intense heat, lose their energy in returning to a lower energy state. Graybody radiant energy is energy emitted due to the temperatures of hot objects within the flame, such as dust or soot, and is responsible for the characteristic orange-yellow color associated with a fire.

Optical sensors are designed to detect either selective radiation or graybody radiation or both, and are usually classified according to the wavelength of the spectrum to which they are most sensitive. Ultraviolet sensors respond to energy emitted between 0.18 and 0.4 um; visible sensors respond to energy between 0.4 and 0.75 um; and infrared detectors respond to energy between 0.75 and 20 um (Litton, 1979).

Warner (1975) considered that the effective range of optical type detectors at normal sensitivity settings was approximately 6 metres and that this range was too limited for practical applications to detection of belt conveyor fires. Litton (1979) considered that optical sensors offered potential for detecting overheated conveyor belt idlers and that their greatest utility would be for protection in high-risk areas or for large equipment. A recent development in the use of an infra-red scanner to detect heating due to deterioration in idler rollers has shown promising results (Grainger, 1984). The basic principle is for the infra-red scanner unit to be mounted over the conveyor towards the delivery end. The conveyor is stopped for a short period (approximately 2 minutes) to allow heat from any source to be transferred to the belt. The belt is then run at normal speed and the infra-red scanner will detect all heat sources and identify the location of the source along the conveyor. The device is extremely sensitive and has identified idler rollers at the very earliest stages of

deterioration i.e., long before any question of significant temperature rise. In Robinson Dames & Moore's opinion, the infra-red scanning of a moving belt conveyor is a significant development in fire protection since it is applicable to installed conveyors where the replacement of existing idlers by self-locking idlers may be prohibitive for logistical or economic reasons.

Highton and Cooper (1982) reported the use in the United Kingdom of the Probeye Infra-red Viewer for the detection of incipient spontaneous combustion and which could be used for the detection of incipient combustion at points along underground conveyors. The instrument converts infra-red radiation to corresponding levels of visible light, producing a display in red light on a viewing screen and giving a readily discernible temperature pattern of all objects in the viewer's range. The instrument weighs 3.27 kilogram and is powered by two rechargeable 9-volt batteries. A small cylinder of argon gas, attached to the instrument, is used to cool the detector heads. The system of operation is to "set" the instrument at the outbye end of the district by adjusting the brightness/contrast controls to give a suitable background level dependent on the ambient strata temperature. The roadway to be examined is inspected by traverses of 10- to 15-metre lengths. The traverse can be carried out in only a slightly longer time then walking and enables places out of normal reach to be easily surveyed. The disadvantage of the instrument is that it only detects surface temperature and has no depth of penetration.

Criddle (1981) referred to the development of a hand-held thermal viewer which operates on a similar principle to the Probeye, but is thermo-electrically cooled and, therefore, eliminates the need for argon gas at high pressures.

4.2.4 Gaseous Emissions

As a result of combustion, gases are added to the atmosphere of which the principal gas, present in almost all fire situations, is carbon monoxide (CO). Professor Graham (1930) showed how the ratio of carbon monoxide present to oxygen deficiency (compared to the proportion of oxygen found in normal fresh air) is independent of changes in the ventilation airflow. Chamberlain (1970), in investigations of coal oxidation at temperatures ranging from 30 to 200°C, concluded that carbon monoxide was the most sensitive gas for indicating the onset of coal heating. Dalzell (1976) noted that carbon monoxide early warning detectors are anticipated to function at concentrations well below 20 parts per million and that, under these conditions, carbon monoxide/oxygen deficiency ratios are not appropriate. Dalzell (1970) concluded that carbon monoxide as a "state of the art" indicator appeared to be a viable and practical approach to early warning fire detection in coal mines without diesel equipment, provided that the instrumentation is sufficiently responsive, accurate and rugged.

In 1970, in the coal mines in the United Kingdom, approximately 30, Unor I gas analysers were in use underground to monitor carbon monoxide concentrations (Institution of Mining Engineers, 1970, 1971). The gas analyser operates on the infra-red absorption principle and is designed to operate with indicated ranges of 0-10 and 0-300 parts per million and was claimed to have a limit of error of less than 2 percent of the full scale value. Dalzell (1976) reported that in Germany, in 1971, approximately 430 carbon monoxide monitoring units of the non-dispersive infra-red type were in use in underground coal mines.

More recent developments in the detection of carbon monoxide comprise solid state, and electrochemical detectors (Griffin, 1979). Solid state detectors, such as Taguchi-type sensors, use a selection of bulk n-type material metal oxides such as SnO_2 and Fe_2O_3 impregnated in a solid state matrix material supported by conductive filaments. The presence in air, of reducing gases, such as carbon monoxide, through adsorption and electron

exchange, causes a change in the resistance of the oxide film which can be measured, and which is proportional to the total gas concentration. Criddle (1981) considered that Taguchi-type sensors could be used to give an early warning for both the gradual increase in carbon monoxide produced from a waste heating or the rapid increase as a result of a roadside heating or open fire.

Electrochemical techniques for CO sensing, as in sensors of the Ecolyzor type, depend on the electrochemical reaction of the detected gas, oxidized or reduced at an appropriate electrode potential, producing an electric current which, under membrane diffusion controlled conditions, is directly proportional to the gas concentration. These devices are subject to interference from gases other than that desired for detection, but are capable of precision calibration making them useful as an analytical device (Griffin, 1979).

Hertzberg et al. (1977), in studies of incipient combustion and detection, concluded that although carbon monoxide detection is sensitive for self-heating coal, it is relatively insensitive to incipient fires in wood and plastic combustibles. The latter conclusion was supported by van der Walt (1976) who reported that an analysis of prop wood fires and fires in gold mines in South Africa showed that very little carbon monoxide is present during the initial, oxygen-rich stages of a fire but there is always a high concentration of carbon dioxide (CO_2). It was concluded that, during any stage of combustion, the increase in carbon dioxide concentration above the normal atmospheric concentration is found always to be higher than that of carbon monoxide. As a result of these conclusions, fire detection in South African gold mines is based upon the use of the Becon MK II ionization-type smoke detector in conjunction with the Spanair gas analyzer. In the Spanair, the infra-red energy emitted by a nickel-chrome ribbon is reflected between convex gold-plated mirrors at opposite ends of a cylindrical gas chamber and then filtered to an indium-antimonide photo-detector. The spectral filter allows infra-red light between 4.22 and 4.31

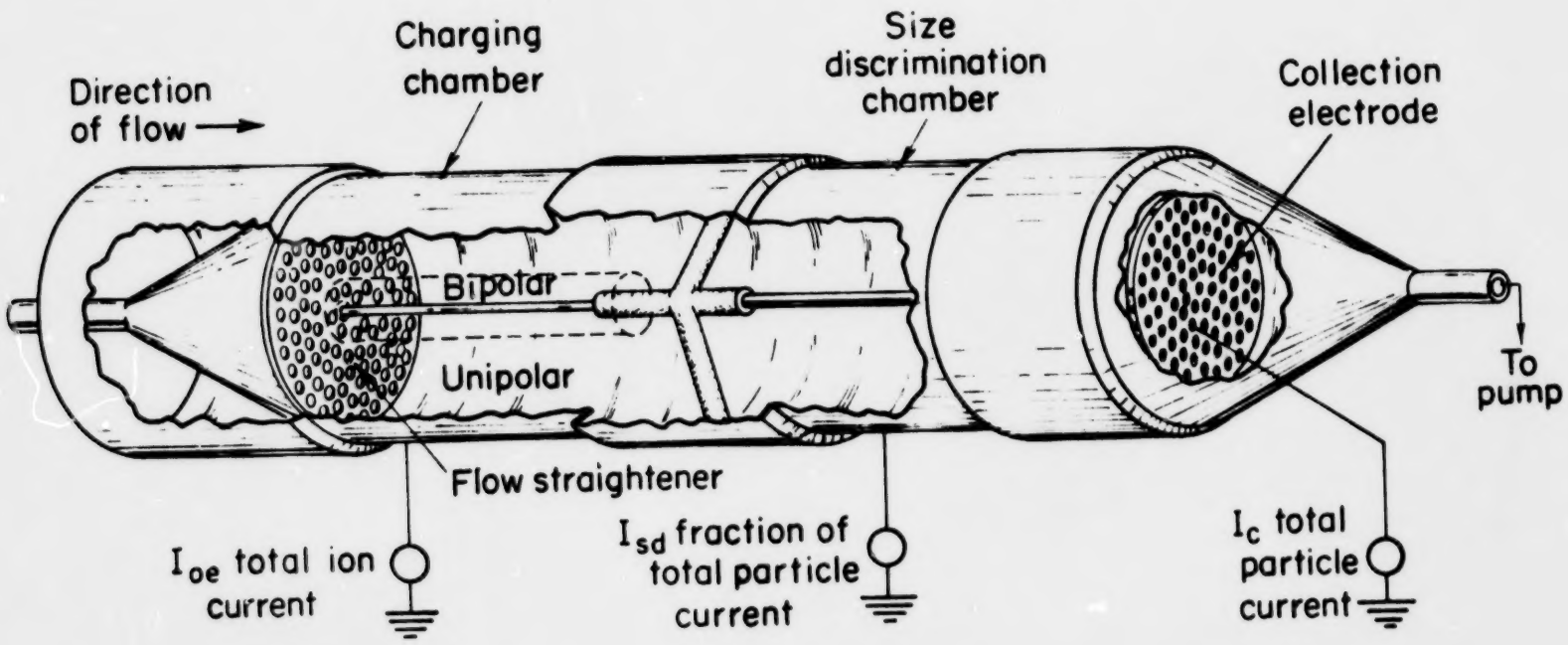
um to pass through to the detector, and because CO_2 is the only gas to have an absorption wavelength between these two values, it is the only gas to which the photo detector will react.

4.2.5 Sub-micrometer Particulates

In the United States, studies of incipient combustion and its detection showed that the earliest indication of a slowly developing combustion was the generation of large quantities of sub-micrometer particulates (Hertzberg et al., 1977). It was concluded, by Litton, (1977), that although both ionization and photoelectric types of smoke detectors were capable of detecting these particles of combustion, the sensitivities of the sensors were too low to detect submicrometer particle densities during incipient combustion processes. Consequently, the U.S. Bureau of Mines initiated a program to develop a sensor capable of measuring, accurately and reliably, sub-micrometer particulates.

The prototype ionization attachment incipient fire detector, developed by the U.S. Bureau of Mines, is shown in Figure 2.

Particles generated during incipient combustion stages flow through a filter and cyclone assembly designed to eliminate interferences from coarse atmospheric dusts and then into the ionization chamber which is essentially unipolar with positive air ions. Particles acquire some net charge as they pass through this region and give up their charge at a third collection electrode located downstream of the ionization chamber. Relinquishing the charge at the collection electrode produces a current flow (I_c) which is proportional to the number density of particles. A second electrode configuration may be inserted between the ionization chamber and the collection electrode to provide for a size analysis of the particulates, should the need arise. Additionally, the reduction in current (I_{oo}) at the outer negative electrode of the primary ionization chamber may be measured



(1) Bureau of Mines Report of Investigations, RI 8242, 1977

FIGURE 2 - DIAGRAM OF PROTOTYPE IONIZATION ATTACHMENT INCIPIENT FIRE DETECTOR (1)

in conjunction with the collection electrode current. This simultaneous measurement of both currents introduces a reliability factor which may be needed in many applications (Litton, 1977).

Litton (1979), in an overview of state-of-the-art technology in fire detectors, concluded that carbon monoxide and sub-micrometer particulate monitors offered the greatest potential for use as fire detectors. However, in a further study of product-of-combustion fire detection in mines, Litton (1981) considered that the results of the study clearly implied that sub-micrometer particulate detectors offered significant improvements over either carbon monoxide or carbon dioxide detectors.

4.3 EQUIVALENCY TESTING OF FIRE DETECTORS

In the United States, under the Code of Federal Regulations, Title 30, Mineral Resources, thermal point type detectors, or other detectors providing equivalent protection, are required to be installed on each underground conveyor. Miller et al. (1979) described tests to determine if product of combustion sensors afforded protection equivalent to heat activated fire detectors. The product of combustion sensors were of the Ecolyzer type in Series 4000 having a range of 0-50 parts per million of carbon monoxide. Heat activated fire sensors were represented by arrays of 6 thermocouples at each of four locations. Equivalency was considered to exist between the carbon monoxide and thermal detectors when the spacing between the carbon monoxide monitors and the "alarm" concentrations were such that the carbon monoxide monitors would detect a fire at the same time as properly spaced point type heat sensors. It was concluded (Miller et al., 1979) that low level carbon monoxide monitors may provide equivalent protection to that provided by thermal point detectors but that equivalency is dependent on the proper spacing of the carbon monoxide monitors which is a function of contaminant travel velocity and which is dependent on the air velocity in the roadway and the distance from the source of the carbon monoxide to the monitor.

Litton et al., (1982) considered that the equivalency testing conducted by Miller (1979) was based on the implicit assumption that the thermal sensor requirements in the United States provided the necessary degree of protection and that no account had been taken of the effects of rate of development of a fire. It was considered that detection and alarm, regardless of sensor type and sensing methodology, must be achieved at some point in time before the fire reaches a critical size. Litton et al., (1982) defined criticality as that size of fire for which belt ignition and subsequent flame spread down the belt is assured. Based on experimental results, Litton et al, (1982) considered that it was possible to quantify characteristic fire growth rates and critical fire sizes as a function of the ventilation velocity for fires that develop along conveyor belt haulageways. The data indicated that, at the onset of flaming combustion, complex patterns of stratification and recirculation result, which can drastically influence the vertical and horizontal placement of fire sensors. In the near-field, buoyant stratification dictates that sensors be placed in the upper quadrant of the belt entry and may result in a combustion product travel velocity which is a fraction of the initial average ventilation velocity, thus dictating a reduced horizontal spacing between sensors. Litton et al., (1982) concluded that, in order to satisfy the constraints of detection at some stage of fire growth prior to the attainment of the critical size, thermal sensing systems at the ventilation velocities studied must be essentially continuous along the haulageway, if the presently accepted alarm threshold of 57.2°C is to be used. It was further concluded that "equivalent" product of combustion sensing systems could have sensor locations spread at distances measured in hundreds of metres.

Further consideration of the location and distribution of product of combustion fire sensors in mine entries was given by Litton (1983) who developed guidelines, based upon sensor alarm thresholds, ventilation flow rate, and mine entry dimensions, for the detection of fires from coal and wood. Litton concluded that product of combustion fire sensors should be

located at a vertical distance from the entry roof not exceeding 25 percent of the average entry height and at a horizontal position within 50 millimetres of the approximate mid-point of the entry.

4.4 EQUIPMENT ANCILLARY TO FIRE DETECTION SENSORS

In addition to a change in the ambient temperature resulting from a fire, changes in the static pressure and the ventilation flow may also occur. If the fire is large enough, the ventilation flow could be adversely affected to the extent of causing a reversal in the direction of flow. Litton (1979) considered that anemometers or velocimeters could be used to sense extreme changes in flow conditions should other fire protection measures fail. Continuous monitoring of volume airflow has been made possible by development of velocity monitors of the swing gate, pitot tube, grid and venturi types (Goddard, 1977). Currently two main types of air velocity monitor are used. The anemometer type incorporates a vane assembly with a means of detecting the change in capacitance as each vane passes a fixed point. The frequency of the pulses is converted into a direct current analogue signal and provision is made, through damping of the responses, for the instrument to give an indication of mean air velocity. The monitor has a range of 0 to 10 metres per second in three stages and readings are accurate to $\pm$6 percent. The ultrasonic vortex sensing monitor incorporates a strut in the path of the airstream which causes vortices behind the strut at a frequency corresponding to air velocity. The vortices are detected by ultrasonic transducers and converted to direct current analogue signals. The range is 0 to 10 metres per second in three stages and the reading accuracy in the uppermost range is $\pm$0.3 metres per second. Neither of these instruments is intended for use in a duct or other restricted area.

4.5 SUMMARY

Fire detection systems are based on the principle that a fire causes a measurable change in the ambient condition. In European underground coal mines, early warning fire detection systems are based, primarily, on the

detection of carbon monoxide. In the United States, fire detection systems are based on thermal point type detectors or such other detectors as may provide equivalent protection. Equivalency has been established for carbon monoxide monitors in comparison with thermal point type detectors. However, a major thrust of research conducted by the U.S. Bureau of Mines, has been towards the development of an ionization-type detector of sub-micrometer particulates which provide the earliest indication of incipient combustion. Research in the United States has also been directed towards the quantification of fire growth rates and critical fire sizes, as a function of ventilation velocity along conveyor belt haulageways, and to the location and distribution of product-of-combustion sensors in mine entries. In general terms, it may be concluded that a total fire detection system would incorporate a number of sub systems in each of which the applied detection methodology would depend on detailed consideration of variables such as combustible loading, ventilation patterns, tolerable response times, and potential origin of fires. In Robinson Dames & Moore's opinion, the infra-red scanning of a moving belt conveyor is a significant development in fire protection since it is applicable to installed conveyors where the replacement of existing idlers by self-locking idlers may be prohibitive for logistical or economic reasons.

5. MONITORING

5.1 INTRODUCTION

As a part of this study, Robinson Dames & Moore has examined monitoring with computer-based remotely operated systems and has compared such systems with labour-intensive site monitoring and with combined approaches.

5.2 CENTRAL CONVEYING CONTROL SYSTEMS

After 1955, the increase in coal face mechanization resulted in the development and installation of conveyor belt and bunker systems to handle the high potential outputs. The systems were labour-intensive in terms of the numbers of men employed at transfer points, on patrol, or operating bunkers. Additionally, the complexity of transport systems in many mines made it almost impossible for men to continuously monitor their operations (Hartley, 1980). The remote control of conveyors was developed, primarily, to effect reductions in elsewhere-below-ground manpower, and also to ensure an optimized flow rate throughout the whole coal clearance system (Massey, 1976).

The conveyor belt protection devices, described in Section 3.5 of this report, mainly comprise of transducers capable of converting the data obtained into electrical impulses. A hard-wired transmission system passes the electrical impulses to a control center and returns electrical control signals to the equipment. The control systems tend to work on the time division multiplexed basis with the control system recognizing the time division or interval between impulses. Modern central conveying control systems utilize surface control centers to collect the electrical signals and to transpose them into a form suitable for display. By using a computer program to compare the data with defined standards and either perform

control procedures or issue warnings when pre-set limits are exceeded, it is possible for one control room operator to control 100 conveyors or other plant from the control desk (Massey, 1978).

Massey (1978) described the central conveying control system installed at Bentley Colliery which covers 20 conveyors and three bunkers. Each transfer point in the conveyor system is provided with optional local control and is monitored centrally for operation and faults in terms of the following fault conditions: slip, motor overheat, misalignment, bearing overheat, blocked chute, torn belt, brake overheat, smoke, brake alarm, water curtain, electrical fault, frozen contactor, outstation malfunction, pre-start warning failure, stop for local selection, stop for remote selection, signal stop, signal lockout, local lockout, local stop, surface operator stop, and program stop. In the event of a fault developing in the system, the conveyors are automatically stopped by the computer, and, as soon as the fault is cleared, the conveyor sequence is automatically re-started.

Hartley (1980) considered that the introduction of central conveying control systems resulted in the following tangible benefits:

- Manpower savings.
- Prediction and avoidance of major belt drive breakdowns during production.
- Improved running time of gate belts with a faster starting sequence.

Operational experiences with central conveying control systems resulted in the following conclusions:

- Remote monitoring and control of coal transport systems demands a high standard of design, installation and maintenance on conveyors, transfer points and bunkers. The computer system monitoring, logging and reporting facilities persistently highlights weaknesses in the transport system.

- The diagnostic facilities within the computer system assist in identifying the faulty part, thus reducing fault-finding and repair times.

The literature makes little reference to the contribution of control conveying systems to fire prevention, detection and suppression on underground coal mine conveyors. Hartley (1980) noted that central systems enabled blocked chutes and torn or slipping belts to be brought to the attention of the belt patrolman with the minimum of delay and that the system identified design weaknesses and the need to improve transfer points, chutes, and belt maintenance.

5.3 REMOTE ENVIRONMENTAL MONITORING

The instrumentation for fire detection in underground coal mines, previously described in Section 4 of this report, which depends upon the sensing of changes in ambient conditions, may provide either local or remote warnings. Remote warnings may be provided by the telemetric transmission of sensed data or by the pneumatic transmission of mine air samples to the surface for analysis. The latter technique, known as the tube bundle system (National Coal Board, 1977) consists of multi-cored tubes, usually up to 12 in number, housed within armoured hose and suspended through mine roadways to the selected sampling sites. The tubes are channelled to a surface extractor pump adjacent to a gas analyzer house. Each sample is analyzed for carbon monoxide, carbon dioxide, and methane by the infra-red absorptiometric method and for oxygen by a paramagnetic method. Nitrogen is deduced by difference. The system is operated by a micro-processor which is programmed to calculate the Graham ratio and oxygen deficiency. The system can handle samples at the rate of one per minute, though the actual sampling time depends also upon the distance from the sampling point to the surface. Sample travelling is of the order of 80 metres per minute. The gas sample is first cooled and then passed through the gas analyzer. Accuracy of the analyzers is maintained by an automatic zeroing system that operates at the start of each sampling sequence and, in addition, known test samples are processed twice per day.

The tube bundle system provides a full air analysis for the selected points. Analysis on the surface has two main advantages:

a) Sampling through the tube bundles can always be maintained, even when the supply of power to a district is cut off and men are withdrawn.

b) The system can monitor a large number of points and can be extended almost indefinitely.

A disadvantage of the tube bundle system has been considered to be that imposed time delays due to tube transit times and sequencing times are unacceptable for applications where the rate of development of a particular hazard can be quite rapid. This disadvantage can, to some extent, be overcome by moving the analyzer underground and telemetering analysis results to the surface. This reduces the response time and allows the system to be used as a general fire alarm whereas surface analysis is primarily suitable for spontaneous heating alerts. Litton (1983) developed design criteria to assess the limiting time responses of tube bundle systems and considered that such systems could be developed to monitor for hazards that develop quite rapidly.

An alternative to the tube bundle system for remote monitoring of the environment is provided by the telemetric transmission of sensed data. Systems employing telemetric tramsission consist of three main elements:

a). Outstations, at selected points underground, to receive signals from transducers which monitor the ventilation.

b). A surface primary computer which scans the outstations in a predetermined order by time division multiplexing. Information fed back from these stations is recorded on a printer. An integral part of this computer is the control console with a function keyboard and twin monitor screens for graphic display. Also available are remote display terminals for use away from the central station.

c). A secondary computer, of greater capacity than the primary, for long term storage of data and feedback of information upon demand.

Normally, production districts and development drivages will be monitored for:

- airflow, using a transducer with an instrument having three suitable velocity ranges
- full air analysis
- gas flow in the methane drainage range
- gas purity in the methane drainage range
- suction in the methane drainage range
- smoke detection
- combustible respirable dust levels
- effective temperatures
- noise level indication

Additional functions, upon demand, would be calculation of the Graham ratio and visual display of the position of the sample in relation to the Coward triangle.

The transducers can be sited at selected sampling points. The layout for a typical production district has:

- An outstation sited at the intake entrance to a district; monitoring selected from the list above.
- An outstation in, primarily, working headings; monitoring selected items from the list above.
- An outstation sited at the outer end of the district return; provided with full range of monitoring facilities.

In the development drivages, items are selected as appropriate.

Visual display units on the central control desk are the focal points for information fed back into the system. The normal display is a tabloid showing the monitoring point identified by district name and location and

the status of the various parameters being monitored. The tabloid represents the up-to-date underground condition and forms a general mine display. Other programs are displayed, as required, by typing the appropriate code on the function keyboard. The individual district display repeats the parameters covered by the general mine display, together with district additional functions. Graphics can be established to display current shift, previous shift, and previous 7 days. In effect, they display trends which are on instantaneous recall.

One of the main uses of the system is the early recognition and indication of abnormal environmental conditions. The computer is programmed for parameter norms. Movement away from thse norms is indicated by a series of alerts followed by alarm should the adverse trend persist. With the analogue transducers, several levels of alert can be indicated before alarm is reached. With the digital transducer, only an alarm condition is displayed as there is no graded circumstance.

In the United Kingdom, the National Coal Board has standardized on the Standard Computer System for Mine Operations - MINOS (Bexon, 1977; Chandler, 1978) which may incorporate both the central conveying control system and environment monitoring.

Hartley (1980) considered that the value of remote environmental monitoring could not be estimated in cash terms but the additional twenty-four hour per day, rapid, reliable double check on underground ventilation must create another order of safety for the men and the mine. The presentation of information with automatic warnings, alarms and messages concerning changes in ambient conditions provides an important back-up safety role to the responsible officials underground.

Welsh (1982) studied the use of computerized continuous, remote mine monitoring systems for fire and explosive atmosphere safety in underground coal mines in the United States and concluded that such systems were capable of increasing the safety level in the mine for the following reasons:

a). Monitoring is continuous and can detect hazards occurring in between periodic examinations.

b). Parameters not required in the Code of Federal Regulations can be monitored, which may be site-specific.

c). It performs diagnostic functions that reduce shutdown time on fans or other equipment critical to mine safety.

d). It provides location of hazards or problems, that allows for quick corrective action and aids in the escape of miners.

e). Detection is rapid to allow time for correction of hazards and for escape of miners.

f). Alarms are sent to a manned location on the surface, where a person is on duty who can communicate with personnel underground to notify them of the hazard and aid in their escape.

5.4 LABOUR-INTENSIVE SITE MONITORING

At the inquiry into the Creswell Colliery fire in England, in 1950, considerable time was devoted to discussing the question of the supervision necessary to ensure safety in the conveying system. The question largely resolved itself into one of whether in conjunction with the provision of safety devices of approved worth and a patrol system under which a competent person or persons would keep the whole length of the belts and transfer points under observation during each working shift, or whether there should be in addition to the patrol system, a man in constant attendance at each transfer point. In his Report, the Chief Inspector of Mines & Quarries concluded and recommended that on all trunk belt installations, there should be a regular patrolling system, while the belts are working, and for at least two hours after stopping, and either:

a). Automatic safety control devices fitted at all transfer points at the drive heads or,

b). At transfer points, where no such devices are fitted, a full-time attendant.

In 1951, the National Coal Board issued instructions in promulgation of the latter recommendations and also in relation to the following:

a). The provision in certain conditions of a second intake airway to afford alternative means of escape.

b). The fire-proofing of vulnerable points on conveyor systems and the training of conveyor patrolmen in the use of fire-fighting appliances.

c). The improvement of underground fire-fighting arrangements and equipment.

d). The rapid development, production and installation of fire-resistant conveyor belting.

In 1955, the Committee on Roadway Convevors (National Coal Board, 1955) reported that the belt patrol requirements had been lifted in cases where the belting was fire-resistant throughout. Thus, if automatic safety devices had been fitted at transfer points, the conveyor system would be virtually man-less and subject only to regulatory inspection, clean-up, and maintenance.

Robinson Dames & Moore construes labour-intensive site monitoring to mean the restoration of manned transfer points and systematic belt patrols augmented by belt protection and fire detection devices providing local warning but without the provision of overall remote control and monitoring systems. Belt patrolling is considered by Robinson Dames & Moore to be at a frequency such that the whole length of the intermediate conveyor structure is traversed several times per shift.

The Committee on Roadway Conveyors (National Coal Board, 1955), considered that evidence indicated that patrolling was not wholly effective since fires occurred which should have been prevented, and concluded as follows:

> "The job will be effectively done only if it is clearly understood that the patrolman is responsible for making a careful and thorough examination of the conveyor and the roadway and for removing any accumulations of coal dust which he finds."

Raut (1970) identified the senses of smelling, seeing and feeling as being the main human means of fire detection and Sandys (1970) considered that the use of these senses was fundamental in the detection of fires by the fire patrol method. As an adjunct to the fire patrol, Viljoen (1970) discussed the appointment of Fire Master at some South African mines, whose main functions were to introduce, implement, and control methods of preventing underground fires. In a statistical analysis of coal mine fires in the United States from 1950 to 1977, McDonald and Pomeroy (1980) concluded that 64 percent of the fires were detected by an individual patrolling the mine or investigating an unusual occurrence such as equipment failure or smoke.

In terms of fire prevention on underground conveyors, Robinson Dames & Moore is of the opinion that labour-intensive site monitoring methods contribute to fire prevention as a result of the following:

- Detection of incipient idler roller bearing failure by noise level.
- Frequent removal of coal dust accumulations and spillage.
- Adjustment of rollers to maintain alignment along the intermediate structure.
- Observation of deterioration in roadway conditions which may lead to friction between the belt and obtrusions, and the instigation of corrective actions.

In terms of fire detection, the literature offers no comparison between the effectiveness of the various sensors described in Section 4.2 of this report and human senses across the broad range of potential on-site conditions. It seems probable that there is equivalency in detection on the inbye side of the ventilation flow where there are visible signs of a developing fire. The detection of incipient heating or smouldering fires may go unnoticed by the human senses unless these are augmented by equipment such as hand-held infra-red scanners. The rate of change in ambient conditions is often an indication of the development of abnormal conditions

which may go unnoticed under labor-intensive site monitoring methods but would be recorded by remote monitoring methods. In Robinson Dames & Moore's opinion, labour-intensive site monitoring may provide equivalency of fire detection to that provided by remote environmental monitoring methods subject to the maintenance of manning over twenty-four hour periods.

As described in Section 6 of this report, automatic fire suppression methods are available and are primarily utilized, where required, in the vicinity of the drive-head. In general terms, suppression of fires along the length of the intermediate structure is dependent on the actions taken by on-site labour following fire detection whether by remote or other means. It seems probable that labour-intensive site monitoring offers more immediate fire suppression activity than can be provided by remote monitoring systems simply by the physical presence of trained labour responding quickly. McDonald and Baker (1979) in an analysis of fire data, showed that a fire detected within 15 minutes of development resulted in no, or a minimum of, damage to the mine, 73 percent of the time, and concluded that rapid detection and location of fires is very important in order to control the fire and provide enough time for miners to escape.

In summary, Robinson Dames & Moore considers that a comparison between labour-intensive site monitoring and computer based remotely operated system in relation to underground conveyors indicates some advantages of the former in terms of fire prevention; possible equivalency in fire detection along the intermediate structure; and potential advantages of the former in terms of fire suppression.

5.5 COMBINED APPROACHES

Robinson Dames & Moore is of the opinion that, in practical terms, labour-intensive site monitoring is not an alternative to computer based remotely operated systems due to the numbers of men required to provide equivalent protection and to the deleterious effect which the employment of such numbers would have on productive efficiency and costs of production.

The literature reveals little information on assessments of mine safety following the introduction of remote monitoring and control systems. Consideration of labour-intensive site monitoring reveals advantages of this method compared with remote monitoring in terms of fire prevention and suppression on underground coal mine conveyor systems. Robinson Dames & Moore is, therefore, of the opinion that a combined approach is necessary in which full advantage may be taken of remote control and monitoring for fire prevention and detection, with automatic fire suppression equipment, provided that is supplemented by the maximum amount of labour-intensive monitoring which can be afforded under prevailing mining conditions in order to reduce to a minimum the fire risks associated with underground coal mine conveyor systems.

6. TECHNOLOGY FOR FIRE SUPPRESSION AND CONTROL

6.1 LEGISLATIVE REQUIREMENTS FOR FIRE SUPPRESSION

A comparison of legislative requirements for the provision of equipment for fire suppression in underground coal mines reveals substantial differences between the regulations applicable in Canada, United Kingdom, and United States. The Canadian requirements provide for an adequate supply of stone dust and portable fire extinguishers except where water is provided with equipment which can readily be used in case of fire. Under United Kingdom regulations, the primary requirement is to secure the provision and readiness for use in case of fire below ground of adequate supplies of water and efficient means for delivering it promptly at adequate pressure and in adequate volume. The United States regulations are more specific and more stringent in relation to roadways in which belt conveyors are installed and require the following:

- Waterlines, capable of delivering 3.8 litres per second at a nozzle pressure of 345 kPa, shall be installed parallel to the entire length of belt conveyors with valves for firehose outlets at 90-metre intervals and at least 150 metres of firehose stored at strategic locations along the belt conveyor.

- Deluge-type water sprays or foam generators automatically actuated by rise in temperature, or other no less effective means of controlling fire shall be installed at main and secondary belt-conveyor drives to provide protection for the belt drive and 15 metres of fire-resistant belt and 46 metres of nonfire-resistant belt adjacent to the belt drive.

Specific provisioning to meet legislative requirements are discussed in the following sections.

6.2 FIRE SUPPRESSION EQUIPMENT

6.2.1 Water Supply Underground

In the United Kingdom, water supply for fire-fighting underground is supplied under gravity from a 90,000-litre surface reservoir via pipe ranges of 100- and 150-millimetre diameter. A minimum supply of 3.4 litres per second at 393 kPa must be available from the furthest hydrant in the fire-fighting range, and the minimum supply is designed to give a water jet of 10 metres at a height of 1.8 metres. Fire hydrants are located at 114-metre centres and each hydrant is designed to reduce the pressure and flow in the mains to a safe working pressure of 520 to 620 kPa at 270 to 295 litres per second. Fire hoses of 114-metre length are installed at alternate hydrants and are to NCB specifications.

In the United States, the requirements are explicitly stated in the relevant regulations as indicated in Section 6.1 above.

6.2.2 Portable Fire Extinguishers

In the United Kingdom, the contents of portable fire extinguishers are related to their use on fires as classified generally in accordance with British Standard 4547:1972 Classification of Fires as follows:

Class A - are fires involving solid materials normally of an organic nature (compounds of carbon) in which combustion generally occurs with the formation of glowing embers. These are the most common fires and the most effective extinguishing agent is generally water in the form of a jet or spray.

Class B - are fires involving liquids or liquefiable solids. Flammable liquids may be divided into (i) those that are miscible with water and (ii) those that are immiscible with water.

Extinguishing agents are chosen according to this division and may include water spray, light water, vaporizing liquids, carbon dioxide and dry chemical powders.

Class C - are fires involving gases. Foam or dry chemical powder can be used to control fires involving gases, while water in the form of spray is generally used to cool gas containers or liquefied gases.

Class D - are fires involving metals. Extinguishing agents containing water are ineffective and even dangerous; carbon dioxide and the bicarbonate classes of dry chemical powders may also be hazardous if applied to most metal fires. Powdered graphite, powdered talc, soda ash, limestone and dry sand are normally suitable agents. Special fusing powders have been developed for fires involving some metals, especially the radio-active ones.

Electric Fires - are not now given a separate classification since any fire started by electrical equipment, or involving it, must be in class, A, B, C, or D. The electricity is cut off and the extinguishing method used appropriate to whatever is burning. Only when this cannot be done will special extinguishing agents be required which are non-conductors of electricity and non-damaging to equipment. (These include halons and carbon dioxide; powders can be damaging to delicate electric apparatus).

Water-type fire extinguishers are normally used on Class A fires and are of the gas pressure type in which a cartridge of carbon dioxide is pierced when the extinguisher is activated and the gas forces the water out of the extinguisher.

Foam extinguishers are used as Class B fires and are of the air foam type which produce foam from a solution of foam compound and water. The chemical foam type, which operates by a mixing of chemicals when the

extinguisher is inverted, is no longer used in British coal mines since it does not comply with either National Coal Board or British Standards Institute standards (Colliery Guardian, 1984).

The dry powder type of portable fire extinguisher can be used on all types of fire and the National Coal Board uses the gas cartridge type with sodium bicarbonate based powders. Dry powder has no cooling effect and affords no protection against re-ignition. It is, however, quicker than foam in extinguishing fire and burning liquids (Colliery Guardian, 1984).

6.3 AUTOMATIC FIRE SUPPRESSION SYSTEMS

In the United States, the mining regulations for belt conveyor fire-suppression systems are necessarily based on simulated full scale studies and practical experience (Kuchta, 1978). An evaluation of the existing regulations for water sprinkler, high expansion foam, and multi-purpose dry powder systems was conducted under a contract with the U.S. Bureau of Mines (Warner, 1974, 1975). Water deluge systems were not evaluated because the criteria for water sprinkler systems would also apply to the former. Evaluation was based on full-scale fire and suppression tests conducted in a 1.8- by 4.6- by 53.3-metre simulated belt haulageway using a flame source (61.5 kilojoules per second) and radiation source (approximately 150 kilojoules per second) for igniting conveyor belts and with air velocities of 0.64 or 1.78 metres per second.

6.3.1 Automatic Water Sprinklers

In the test program, the sprinkler system comprised a 50-millimetre main located at the roof of the gallery with 12.5-millimetre branches fitted with sprinkler heads spaced at intervals of 2.4, 3.0, 3.6, and 4.6 metres over the conveyor belt. Each sprinkler head was equipped with a fusible link that was actuated at 74°, 100°, or 138°C. Test results indicated that a single overhead branch line with 12.5-millimetre orifice sprinklers located on 3-metre centres and with actuation temperatures between 93° and

149°C can be adequate for suppressing belt conveyor fires in most situations. An exception to the results was observed at air velocities of 1.78 metres per second which tended to delay sprinkler actuation because of the cooling effect. Kuchta (1978) concluded that, in the latter situations, the maximum actuation temperature should be 107°C, or that the sprinkler spacing should not be greater than 2.4 metres. Although only overhead sprinkler heads appeared to be necessary for fire extinguishment in the tests, previous Bureau of Mine research (Mitchell et al., 1967) demonstrated the need for sprinklers between the top and bottom belt strands in addition to overhead sprinklers.

Warner (1975) and Kuchta (1978) concluded that automatic sprinkler systems are advantageous because of economy, reliability, good suppression capability, moderate water requirements, and minimum maintenance requirements. They are not dependent upon a separate detection system, and the independent actuation of each sprinkler head provides a safeguard against the failure of a given sprinkler. Their primary disadvantage is that they are not practical at freezing temperatures.

6.3.2 High Expansion Foam

Tests of fire extinguishment using high expansion foam were conducted (Warner, 1974) using a foam generator of 142 cubic metres per minute located at the air intake side of the fire and capable of filling 15 metres of the simulated haulageway within 1 minute. Warner (1975) and Kuchta (1978) concluded that high expansion foam at generation rates of 3 metres per minute is effective for extinguishing belt-head fires and its main advantages are rapid fire suppression and low water requirements. Warner (1975) considered a disadvantage of high expansion foam, in situations where there is no alternate path for ventilation air, is the fact that the foam will not reach the roof. Thus, ignition that might occur at the roof might not be extinguished, and might even be fanned by the higher air flow in the space between the foam and the roof, due to the orifice effect of the foam plug.

6.3.3 Multi-Purpose Dry Powder

Tests of fire extinguishment using a monoammonium phosphate dry powder were conducted (Warner, 1974) using a 68-kilogram extinguisher pressurized to 2400 kPa. The tests showed that fire extinguishment with dry powder was rapid and generally occurred wthin the discharge time of 1 minute.

Warner (1975) concluded that an important consideration in the design of a dry powder system is belt surface coverage and that each system must be individually designed to insure that powder will impinge on all belt surfaces likely to become involved in a fire, and no areas should be shielded by decking, conveyor structure members, side enclosures, or any other items that would impede powder distribution. In addition to the disadvantage of the criticality of powder distribution, Warner (1975) considered that powder has little cooling effect and is more likely to result in re-ignition than with water based extinguishants. Other disadvantages include greater vulnerability of the discharge nozzles to damage and the discomfort to personnel who might be in the area during discharge.

6.4 SUMMARY

The legislative requirements for fire suppression in the United States and the United Kingdom are comparable in terms of the provision of a dedicated and adequate supply of water for fire-fighting, with efficient means for delivering the water at adequate pressure and in adequate volume. Canadian requirements are less specific. All, of the countries considered, require portable fire extinguishers at strategic points but the United Kingdom appears to be more stringent in relating the contents of portable fire extinguishers to the fire classifications for which they are most effective. The United States' regulatory requirements are unique in terms of mandatory, automatic fire suppression systems which, on the basis of test results, appear to offer reliability and good fire suppression capability.

Robinson Dames & Moore is of the opinion that further research should be conducted into the need for automatic fire suppression systems in Canadian underground coal mines in relation to the fire hazards of underground belt conveyors and the degree of protection provided by currently available technology.

7. PRESENT AND FUTURE CANADIAN INDUSTRY NEEDS

7.1 INTRODUCTION

The statement of work contained in Appendix A to DSS Contract Serial No. OSQ84-0199 requires Robinson Dames & Moore, through correspondence and telephone conversations, to summarize present and future Canadian industry needs for the prevention, detection and control of fires in underground coal mine conveyor systems as expressed by mine operators and regulatory officials. In pursuance of this objective, Robinson Dames & Moore wrote to the following:

Chief Inspector of Mines, Canadian Department of Labour, Nova Scotia
Chief Inspector of Mines, Ministry of Mines & Petroleum Resources, British Columbia
Director, Mines Inspection Board, Workers Health, Safety & Compensation Board, Alberta
Senior Mining Engineer, Energy Resources Conservation Board, Alberta
Director of Engineering, Cape Breton Development Corporation, Nova Scotia
Mine Manager, Westar Mining Ltd., British Columbia
Mine Manager, McIntyre Mine Ltd., Alberta

In conjunction with responses to its enquires, Robinson Dames & Moore has assessed present and future Canadian Industry needs by comparison between Canadian regulatory requirements and those of selected foreign jurisdictions, and by consideration of the document published by the Minister of Labour, Government of Canada, in 1982 and entitled "Safe Work Practice for Mines - Conveyors, SWP-1-1982", against the background of currently available technology as described in this report.

Robinson Dames & Moore notes that a direct comparison between the regulatory requirements governing coal mining operations in various countries is not strictly valid since codes of practice may be mandated to supplement the regulations. The latter is particularly apposite to the United Kingdom where the National Coal Board issues codes of practice in the form of Production Department Instructions which are mandatory. Grainger

(1984) noted that in the formulation of these codes of practice, the National Coal Board is closely involved with the Mines Inspectorate, safety research establishments of the Health & Safety Executive, and the manufacturers. In contrast, in the United States, the Code of Federal Regulations, Title 30 - Mineral Resources, Part 75 - Mandatory Safety Standards - Underground Coal Mines, is particularly explicit as to the minimum requirements for fire prevention, detection, and suppression associated with underground belt conveyors. It appears to Robinson Dames & Moore that in Canada, regulatory requirements, governing the installation and operation of underground belt conveyors and associated requirements for fire prevention, detection and suppression, are minimal and are unsupported by mandatory codes of practice. Accordingly, Canadian requirements are considered in relation to available technology for fire prevention, detection, and suppression in the following paragraphs.

7.2 FIRE PREVENTION AND PROTECTION

SWP-1-1982 includes no reference to the adequacy of conveyors for the duties required, to the design and installation of chutes and mineral sizers to ensure proper belt loading and minimization of spillage, or to the provision of protective sensing devices other than for the detection of belt slippage. In Robinson Dames & Moore's opinion the selection of conveyors adequate for the duties required is fundamental to safe and efficient conveying practices. Similarly, the design and installation of chutes at transfer and loading points is of importance to achieve correct loading and discharge of the belt and to minimize spillage. The incorporation of blocked chute devices is essential to minimize the potential fire hazard due to friction between the conveyor components and coal spillage.

The requirements for belt slippage detection devices in SWP-1-1982 compares with the United States, Code of Federal Regulations, which additionally requires sequence control devices. Neither of the referenced

documents provide for the additional protective devices for belt alignment, temperature sensors, and torn belts, which substantially contribute to the safety of conveyor operation.

In Robinson Dames & Moore's opinion, SWP-1-1982 should incorporate recommendations to minimize the fire hazards associated with idler rollers by reference to the introduction of fire-resistant greases, "lock-out" type rollers, and to the use of the infra-red scanner to detect hot rollers. It is noted that Section 3.12.7 of SWP-1-1982 requires that the operation of a belt conveyor shall not be continued with missing or frozen idlers. In Robinson Dames & Moore's opinion, the requirement in respect of frozen idlers appears to be excessive in view of the research in the United Kingdom which concludes that locked-out idlers do not constitute a hazard.

The regulations in the United Kingdom appear to be unique in their requirement for the fire-proof construction of transfer and loading points and where a conveyor is operated in a roadway serving a district as a single intake. In Robinson Dames & Moore's opinion, further consideration should be given to the fire-proofing requirement in Canadian coal mines and to the reduction in the use of timber in main arterial roadways.

7.3 FIRE DETECTION

In SWP-1-1982, Section 3.14.4 states as follows:

> "Unless a conveyor belt is attended at the drive pulley end at all times that it is moving, every such conveyor shall be equipped with a device that automatically detects any incipient fire at the drive pulley and actuates
>
> (a) an alarm at a control center that is attended at all times, or
>
> (b) a fire suppression system at the drive pulley."

The foregoing requirement in respect of fire detection may be compared with the Code of Federal Regulations-Title 30 which provides a similar requirement in precise terms for types of fire detectors, locations, and

spacing intervals, and without regard to provision of attendants. In Section 4.2 of this report, Robinson Dames & Moore has discussed the various types of fire detectors and the preferred types used in the coal mines of various countries. There is, clearly, scope to consider, in respect of Canadian underground coal mines, the types of fire detectors which would provide the best means of fire detection and to incorporate such recommendations into a code of practice.

7.4 COMPUTERIZED, CONTINUOUS REMOTE MONITORING SYSTEMS

Robinson Dames & Moore notes the absence in Canadian regulations and in SWP-1-1982 of reference to computerized, continuous remote monitoring systems (CCRMS). Similarly, mining regulations in the United States do not deal with the use of CCRMS and such systems may be used to supplement existing requirements or, if a petition is granted, in lieu of existing requirements. Welsh (1982) noted that in other countries, the safety and production benefits of CCRMS are recognized and provision is made in the regulations as follows:

(1). Regulations in France, Poland, and Germany permit higher methane threshold values if constant methane monitoring is carried out by permanently installed recording instruments that feature teletransmission of results.

(2). Regulations in West Germany, the United Kingdom, the U.S.S.R., and Poland require continuous monitoring of all return airways from coal faces and entry headings by means of permanent methane monitoring devices, with data transmission to central mine control stations and with automatic switch-off devices.

(3). Regulations in Canada and Europe contain safeguard monitoring measures for auxiliary ventilation systems based on automatically functioning airflow and methane monitors.

(4). Regulations in Germany prescribe the use of automatic-recording carbon monoxide-measuring instruments in all belt entries.

7.5 FIRE SUPPRESSION

Canadian regulations and SWP-1-1982 provide for the provision of fire fighting equipment. The requirements contrast adversely with both United Kingdom and United States regulations by lack of precise definition of equipment, location, hose lengths, hydrant types, water availability, water pressures and the need for a dedicated fire-fighting water range.

As noted above, Section 3.14.4 of SWP-1-1982 requires a fire suppression system at the drive pulley. This requirement is similar to that included in the Code of Federal Regulations but differs to the extent that the Code of Federal Regulations specifies deluge-type water sprays or foam generators, automatically actuated by rise in temperature, and also specifies the extent of coverage, arrangement of sprinklers, and other technical details of the systems.

In Robinson Dames & Moore's opinion, further consideration should be given to the provision in Canadian regulations or code of practice of more precise definition of suitable fire suppression equipment for use in Canadian underground coal mines.

7.6 SUMMARY

Robinson Dames & Moore has considered present and future Canadian industry needs, for the prevention, detection, and control of fires in underground coal mine conveyor systems, through correspondence with mine operators and regulatory officials and by comparison between Canadian regulatory requirements and code of practice with those of selected foreign jurisdictions, against the background of available technology. In Robinson Dames & Moore's opinion, the following aspects appear to warrant more detailed consideration either for inclusion in Canadian regulations or codes of practice, or as topics for further research and development:

a). The use of belt protective devices as described in Section 3.5 of this report.

b). A reduction of the fire hazard of the intermediate structure by the use of fire-resistant greases and self-locking idlers on new conveyor installations and consideration of the use of the infra-red scanner on existing installations.

c). The fire-proofing of conveyor belt transfer and loading points and a reduction in the use of timber in main arterial roadways.

d). The types of fire detectors best suited to Canadian underground coal mines.

e). The provision of computerized, continuous remote monitoring systems.

f). The types of fire suppression equipment and the need for a dedicated water supply for fire-fighting.

8. SUMMARY OF CONCLUSIONS AND RECOMMENDATIONS

Robinson Dames & Moore has conducted a review of available technology and industry needs for the prevention, detection, and control of fires in underground coal mine conveyor systems and has formed the following conclusions and recommendations.

Consideration of the data, on the frequency and causes of fires on underground coal mine conveyor systems, results in the conclusion that the ranking, in descending order of fire risks of belt conveyor components, is the intermediate structure, the drive head, the conveyor belting, the tail end, and the tensioning equipment. The major cause of fires on modern belt conveyors is due to the collapse, or other failure, of the bearings of the idler rollers.

Conveyor design technology, lubricant development, and conveyor belting manufacture have combined to reduce the major fire hazard of the idler roller. The introduction, on a commercial basis, of fire-resistant greases and self-locking idler rollers is expected in 1985. Additional protection will be afforded to existing conveyor installations by the recent development of the infra-red scanning of a moving belt which can detect and locate the sources of heat imparted to the belt.

The introduction of fire-resistant conveyor belting to underground coal mines has substantially reduced the fire hazard due to the combustibility of the conveyor belt. Specifications for fire-resistant conveyor belt, and the tests required, vary from country to country but the European Economic Community appear to have reached a measure of standardization in tests which are more exacting than those used, for example, in Canada and the United States.

Consideration has been given to the United Kingdom requirements for the fire-proofing of conveyor belt transfer and loading points. Robinson Dames & Moore recommends further consideration of fire-proofing in Canadian underground coal mines and the need to reduce the utilization of timber in main arterial roadways.

The selection of a conveyor adequate for its duty, correct installation, and regular maintenance are considered to be of fundamental importance in fire prevention and protection of underground conveyors.

Detailed consideration has been given to fire detection methods, equipment and systems. It is concluded that a total fire detection system would incorporate a number of sub systems in each of which the applied detection methodology would depend on detailed consideration of variables such as combustible loading, ventilation patterns, tolerable response times, and potential origin of fires.

Available technology for monitoring with computer-based, remotely operated system has been reviewed and a comparison made between those systems and labour-intensive site monitoring and with combined approaches. Robinson Dames & Moore concludes that a comparison between labour-intensive site monitoring and computer based remotely operated system in relation to underground conveyors indicates some advantages of the former in terms of fire prevention; possible equivalency in fire detection along the intermediate structure; and potential advantages of the former in terms of fire suppression. Robinson Dames & Moore concludes that, in practical terms, labour-intensive site monitoring is not an alternative to computer based remotely operated systems due to the numbers of men required to provide equivalent protection and to the deleterious effect which the employment of such numbers would have on productive efficiency and costs of production. Robinson Dames & Moore is, therefore, of the opinion that a combined approach is necessary in which full advantage may be taken of remote control and monitoring for fire prevention and detection, with automatic fire suppression equipment, provided that is supplemented by the maximum amount

of labour-intensive monitoring which can be afforded under prevailing mining conditions in order to reduce to a minimum the fire risks associated with underground coal mine conveyor systems.

As a result of its review of available technology for fire suppression and control, Robinson Dames & Moore recommends that further research should be conducted into the need for automatic fire supression systems in Canadian underground coal mines in relation to the fire hazards of underground belt conveyors and the degree of protection provided by currently available technology.

Robinson Dames & Moore has considered present and future Canadian industry needs and concludes that more detailed consideration is warranted of the following:

a). The use of belt protective devices.

b). The potential reduction of the fire hazard of the intermediate structure by the use of fire-resistant greases and self-locking idlers on new conveyor installations and consideration of the use of the infra-red scanners on existing installations.

c). The fire-proofing of conveyor belt transfer and loading points and a reduction in the use of timber in main arterial roadways.

d). The types of fire detectors best suited to Canadian underground coal mines.

e). The provision of computerized, continuous remote monitoring systems.

f). The types of fire suppression equipment and the need for a dedicated water supply for fire-fighting.

APPENDIX 1

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APPENDIX 2

List of Those With Whom Robinson Dames & Moore Corresponded During The Study

LIST OF THOSE WITH WHOM ROBINSON DAMES & MOORE CORRESPONDED DURING THE STUDY

Canada Centre for Mineral and Energy Technology, Energy Mines and Resources, Canada.

U.S. Bureau of Mines, Pittsburgh, Pennsylvania.

Institute of Mine Hygiene, Hasselt, Belgium.

Mining Research and Development Establishment, National Coal Board, Stanhope Brethy, England.

IEA Coal Research, London, England.

Safety in Mines Research Establishment, Sheffield, England.

Centre d'Etudes et de Recherches des Charbonnage de France, Paris, France.

Steinkohlenberghauverein, Essen, West Germany.

Australian Coal Industry Research Laboratories, Maitland, Australia.

Central Mining Institute, Ministry of Mining and Power, Katowice, Poland.

Montan-Consulting GMBH, West Germany.

H.M. Chief Inspector of Mines, London, England.

Chief Inspector of Mines, Canadian Department of Labour, Nova Scotia.

Chief Inspector of Mines, Ministry of Mines & Petroleum Resources, British Columbia.

Director, Mines Inspection Board, Workers Health, Safety & Compensation Board, Alberta.

Senior Mining Engineer, Energy Resources Conservation Board, Alberta.

Director of Engineering, Capte Breton Development Corporation, Nova Scotia.

Mine Manager, Westar Mining Ltd., British Columbia.

Mine Manager, McIntyre Mines Ltd., Alberta

Chief Engineer, National Coal Board, London, England.

Head of Information Services, National Coal Board, London, England.

Dowty Meco Ltd., England

Huwood Ltd., England

Fenner & Co., England and Canada

Universal Conveyors Ltd., England

Holywell Mining Group, England

The Hanmade Convevor Co., Ltd., England

Conspec, Ontario, Canada

APPENDIX 3

Design of Transfer and Loading Points
and Ancillary Equipment

DESIGN OF TRANSFER AND LOADING POINTS AND ANCILLARY EQUIPMENT[1]

Transfer and loading points should be designed in detail and not left to improvisation. Constructional drawings of the components should be prepared and preserved for repeated use. Standard patterns should be drawn up locally and employed wherever suitable.

Transfer and loading point equipment should be made by suitable manufacturers or at central workshops. Where possible, construction should be sectionalised to facilitate transport and standardisation of parts.

Chutes should be carefully designed and installed so as to deliver the load on to the receiving belt centrally and at the speed and in the direction of the latter. Troughed chutes are advantageous. Provision should be made for adjusting the length and slope of the chute. The gap for the free fall of the coal should be as small as possible and a chute which delivers on to a conveyor already carrying coal should have a hinged or flexible bottom flap to allow large lumps to pass under it.

To prevent damage by objects jamming between the chute top and the drum, a strip of flexible non-flammable material should be attached to the top edge of the chute. Devices such as the Crossland Chute which stops the belt when congestion occurs at the chute top are recommended.

Where two or more streams of coal converge, each of them should be fed into a hopper by means of suitable chutes, or a short feeder or transfer conveyor should be used. The latter is particularly useful where height is limited.

In addition to the help given by the use of troughed bottom chutes, the following assist in centralising the load: --

(i) skirt plates or centralising hopper plates;
(ii) wing-idlers with an increased troughing angle;
(iii) rapping rollers which shake fine material from the edge of the belt towards the centre.

The idlers at the point of impact should be close-spaced to prevent belt sag. Cushion or impact idlers should be used. Increased support by idlers in sets of five instead of three is advantageous for heavy duties.

For dust suppression measures at transfer and loading points, sprays are most effective when used to wet the coal on the belt a few yards before it reaches the delivery drum. In difficult cases the chute should be

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[1] Extracted from the Report of the Committee on Roadway Conveyors (National Coal Board, 1955).

enclosed and water sprays installed inside it, but the enclosure should be fitted with inspection doors and removal covers. To prevent dust percolating through hook type belt joints, sealing strips should be used.

Belt cleaning devices such as the bar scraper serve a useful purpose though no completely effective type has yet been evolved. They should be installed immediately behind the delivery drum on the return side. The dust scraped off the belt should be collected and discharged (so as not to raise it into the air) either into a tub or on to the succeeding conveyor. Another method of reducing dust deposition from the belt is to reverse it so that the dirty side remains uppermost for the return run.

POOR
QUALITY
ORIGINAL